ENDEAVOUR

UNIVERSITY OF PENNSYLVANIA
LIBRARY
FEB 4 1957
PERIODICALS

Volume XVI Number 61

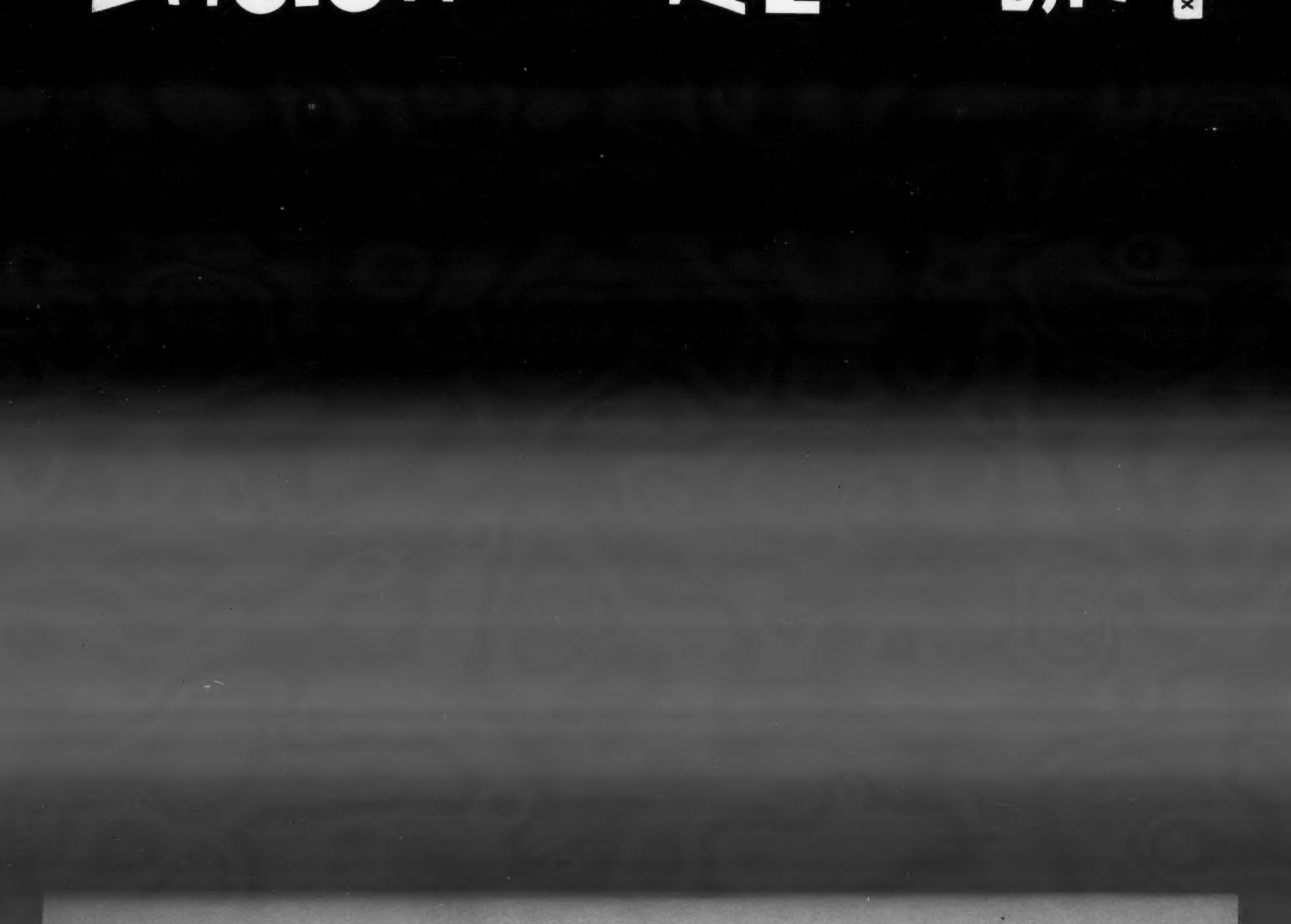
JANUARY 1957

ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, occasional articles from overseas contributors are included and impartial reference is made to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for ENDEAVOUR. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

The drawing on the cover is of the bark Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*



ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME XVI January 1957 NUMBER 61

CONTENTS

070.432:92:538.56
Editorial: Heinrich Hertz (1857–1894) 3

In Memoriam: John A. Wilcken (1881–1956) 4

539.62:531.4
Adhesion and Friction — F. P. BOWDEN, C.B.E., Sc.D., F.R.S. — 5

591.185.6
Animal Photosensitivity, with Special Reference to Eyeless Forms — N. MILLOTT, M.Sc., Ph.D. — 19

533.5(091)
The Early History of the Vacuum Pump — E. N. DA C. ANDRADE, D.Sc., Ph.D., LL.D., F.R.S. — 29

681.14:621.37/.38
Recent Developments in Electronic Computers — J. M. M. PINKERTON, M.A., Ph.D. — 36

551.594.5
Polar and Tropical Aurorae — JAMES PATON, M.A., B.Sc., F.R.S.E. — 42

547.962.4:577.18
The Structure of Insulin — F. SANGER, B.A., Ph.D., F.R.S., and L. F. SMITH, Ph.D. — 48

049.3
Book Reviews 54

Short Notices of Books 59

Notes on Contributors 60

Some Books Received .. .. Cover iii

Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Editorial Assistant (Foreign Editions): G. N. J. BECK, B.Sc., A.M.I.E.E.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
Communications to the Editor should be addressed to North Block, Thames House, Millbank, London, S.W.1

Heinrich Hertz (1857–1894)

In the hands of the great geometers of the eighteenth century, Newton's law of gravitational attraction was so successful in accounting for the observed motions of the planets that attempts were made to account for most of the properties of matter in terms of direct attractions or repulsions across space, varying solely with distance.

According to Newton's law of gravitation, the attraction between two bodies depends only upon their distance apart and is not affected by any intermediate matter, but Newton himself was not a believer in action at a distance, in which the intervening medium plays no part. Nevertheless, the doctrine of action at a distance was strongly favoured by the German and French scientific schools during the nineteenth century. In the hands of W. Weber and others the theory of electricity was developed on this basis to a state of high perfection. But so many different hypotheses were involved that they became very unmanageable.

The English school of physicists, on the other hand, did not favour the doctrine of direct action at a distance. Faraday firmly believed that the action between two electrically charged bodies was transmitted through and by the medium between them. To him it was inconceivable that direct action between bodies separated in space was possible without any change taking place in the intervening medium. He pictured the latter as the seat of a system of stresses, which could be represented by an attraction or tension along the lines of electric force at every point, together with a lateral pressure or mutual repulsion of these lines.

The translation of Faraday's ideas into a mathematical form was the great work of Clerk Maxwell. His theory, in its fully developed form, was published in 1873 in his classic treatise on 'Electricity and Magnetism', in which he showed that all electric and magnetic phenomena could be reduced to stresses and motions of a material medium. He demonstrated that the propagation of electric disturbances resembles that of light, and he did not hesitate to assert the identity of the two phenomena. He pointed out that if the medium required for the explanation of electromagnetic phenomena is the same as that required for the explanation of the phenomena of light, the velocity of light in vacuo should be numerically the same as the ratio of the electromagnetic and electrostatic units. The best determination at that time appeared to confirm that this was so. Hence, Maxwell concluded, 'we can scarcely avoid the inference that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena.'

Maxwell's theory involved novel conceptions, in particular the conception of a displacement current in a dielectric medium, proportional to the rate of increase of the electric force in the dielectric, which produces the same magnetic effects as a true current. By including the displacement current as a continuation through the dielectric of the current employed in charging a condenser, the current became a circuital vector; it could be regarded as flowing in a closed circuit. To most of Maxwell's contemporaries these conceptions were so far removed from contemporary views based on action at a distance that they found great difficulty in accepting them. It was largely due to the work of Heinrich Hertz, the centenary of whose birth occurs this year, that Maxwell's theory was established and became generally accepted. Hertz discovered the electric waves whose existence had been deduced by Maxwell as an essential consequence of his theory, and showed that their properties were similar to those of light waves. He thereby provided the experimental proof of the hypotheses on which the theory was based.

Hertz was born on 22nd February 1857 in Hamburg. While attending the high school of his native town, he spent much of his leisure time constructing optical and mechanical instruments. At the end of his school career he decided to become an engineer; as his studies progressed, however, he became increasingly attracted to pure science, and after two years he decided to abandon the engineering training in favour of an academic career. In the autumn of 1878 he went to Berlin and worked in the laboratory of Helmholtz, who quickly realized that in Hertz he had a pupil of quite outstanding talent and who, in October 1880, appointed him his assistant.

In 1883 Hertz became a *Privatdozent* at Kiel, where he began a serious study of 'Maxwellian electromagnetics' and in 1884 published a paper in which he attempted to justify Maxwell's equations on theoretical grounds, reaching the conclusion that for various reasons Maxwell's system was to be preferred to the opposing system based on direct action at a distance. On his appointment in 1885 as Professor of Physics at Karlsruhe, Hertz turned his attention to the possibility of

verifying Maxwell's theory by direct experiment.

In his first experiment, a piece of copper wire was bent into the form of a rectangle, leaving a short air gap between the ends of the wire. When this was connected by a wire to a circuit through which the spark discharge of an induction coil was passing, he found that a spark passed in the air gap of the open circuit. He next found that the spark could be induced in the open circuit in the absence of any connection with the oscillating circuit, provided that the dimensions of the secondary circuit were such that it was nearly in resonance with the primary circuit. The open circuit thus gave him a method of detecting electrical effects at a distance from an oscillating circuit, all that was needed for observing the propagation of electric waves in free space.

Hertz constructed an oscillator consisting of two sheets of metal in the same plane, each carrying a wire projecting towards the other sheet and terminating in a knob, which was excited by connecting it to the terminals of an induction coil. The small capacitance and self-inductance of this oscillator provided him with waves of sufficiently short wavelength, about 24 cm, to be manageable in his laboratory. His detector was of dimensions such that its free period of oscillation was equal to that of the primary oscillator.

He first showed that the observed phenomena were modified if an insulating substance were brought into the vicinity of the apparatus, thus proving that electrical disturbances in insulators are accompanied not merely by electrostatic actions but also by electromagnetic actions. By transmitting the disturbance from the primary oscillator along two different paths, through the air and along a wire, he obtained interference effects, proving that the electromagnetic actions are propagated with a finite velocity. From further experiments he concluded that the velocity of propagation was of the same order as the velocity of light.

Further experiments established the essential similarity of electric waves and light waves. By reflecting the electric waves from the surface of a wall, standing waves were produced by interference between the direct and reflected beams. By reflecting them from a metal sheet he showed that the angles of incidence and reflection were approximately equal. By transmitting the waves through an opening in a screen, he proved that they were propagated in a straight line with diffraction effects. Refraction of the waves was obtained by passing them through a prism of hard pitch, and polarization was obtained by passing them through a grating of parallel metallic wires.

These experiments were supplemented by theoretical investigations. He analysed, on the basis of Maxwell's theory, the disturbances emitted by his oscillator; he also presented the general content of Maxwell's theory for bodies at rest and extended Maxwell's equations to material bodies in motion in the field.

In 1889 Hertz received a call to the University of Bonn as Professor of Physics and during the few remaining years of his life was occupied with logical discussion of the fundamental principles of mechanics, from the most general standpoint. In 1893 he became ill and after much suffering died on 1st January 1894. His death, at a comparatively early age was a great loss to science.

In memoriam: John A. Wilcken (1881–1956)

It is with profound regret that we record the death—on 9th October 1956, in his seventy-sixth year—of Dr John Adolf Wilcken, who had been Foreign Editor of ENDEAVOUR since the journal's inception in 1942. To the devoted and meticulous care that he gave to the preparation of the four foreign language editions of ENDEAVOUR is due in large measure the success it has achieved abroad.

Born in Denmark in 1881, he had an exceptional experience of travel and of scientific work, both research and editorial, in many parts of the world. Before settling in England he had travelled extensively in Europe and had held appointments in the United States, Brazil, and Argentina; he was a physics graduate of the Universities of Copenhagen, La Plata, and London. He first came to England in 1919, and was for a short time engaged in research at the Cavendish Laboratory, Cambridge. In 1920 he was appointed lecturer in mathematics at Sunderland Technical College, and four years later went to Armstrong (now King's) College, Newcastle-upon-Tyne, as lecturer in electrical engineering. In 1937 he went to the Institution of Electrical Engineers as editor of Section B of *Science Abstracts*; in 1940 he was appointed sole editor. This appointment he held until 1945, from which date he gave the whole of his attention to the preparation of the foreign editions of ENDEAVOUR.

Adhesion and friction

F. P. BOWDEN

Although the fundamental laws of friction are simple and have long been known, it is only comparatively recently that it has been possible to gain some understanding of the local changes that occur when one solid slides on another under various conditions. Knowledge so gained is not only important for an understanding of the physics of solids, but of great practical significance in such diverse fields as the construction and lubrication of bearings, the polishing of diamonds, the de-icing of aircraft, and the formulation of adhesives.

The experimental laws which govern the friction of solids sliding on one another are very simple. It is usually found that the frictional resistance is directly proportional to the load and is independent of the size of the surfaces in contact. A detailed examination of the contour of solid surfaces offers a ready explanation of these laws, for experience has shown that it is almost impossible, even with the best modern methods, to make a surface which is truly flat. To a person of atomic size an optically or electrolytically polished surface would look like country consisting of valleys and rolling hills differing in height by a hundred atoms or more. Most of the engineer's best surfaces have irregularities which are much greater than this and may be thousands of atoms high: they may be compared with Alpine peaks rather than hills. Putting two solids together is thus rather like turning Switzerland upside down and standing it on Austria, and the area in intimate contact will be relatively small.

Measurements of the electrical conductivity across metal surfaces placed together confirm that the real area of contact is indeed very small. It varies with the load, but for flat steel surfaces it may be less than one ten-thousandth of the apparent area. Such experiments are also interesting in that they show that the real area of contact is almost independent of the size of the surface. It is very little influenced by the shape and degree of roughness of the surfaces. It depends mainly on the load which is applied to them, and is in fact directly proportional to the load. The general behaviour is consistent with the view that the surfaces are held apart by small irregularities. This means that, even with lightly loaded surfaces, the local pressure at these small points of contact is very high and may be sufficiently great to cause the hardest metals to flow plastically. Although the stresses will cause elastic deformation of the metal in the vicinity of the points of contact, the experiments suggest that the summits of irregularities on which the bodies are supported flow plastically and are crushed down until their cross-section is sufficient to enable them to support the applied load. The real area of contact A is given by $A = W/p_m$, where W is the load and p_m is the yield pressure of the metal. This is illustrated in figure 1.

There is strong evidence that the friction of metals is due, in large measure, to adhesion at these contact regions and represents the force necessary to shear these small junctions [1]. As a rough approximation one may therefore write $F = As$, where s is the shear strength of the junctions and F is the friction.

We see that this picture offers a simple explanation of the two laws of friction. First, since A, the real area of intimate contact, is independent of the size of the surfaces, the friction will be independent of this. Secondly, since the real area of contact A is proportional to the load, the friction will be also. If the friction is proportional to the load it means, of course, that the coefficient of friction $\mu = F/W$ is a constant.

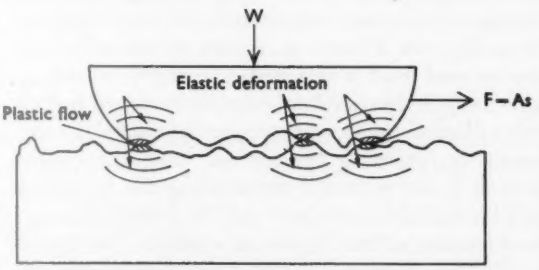


FIGURE 1 – *Two solids placed in contact are supported on the summits of surface irregularities. The pressure exceeds the yield pressure p_m of the solid, which flows plastically until the area of contact A is sufficient to support the load W. Hence $A = W/p_m$. The material around the regions of contact will be elastically deformed. If s is the shear strength of the junctions, $F = As$.*

On occasion the shearing may occur at the interface, but more frequently (because of work-hardening of the contact region) it occurs a little distance beyond it. A metal fragment is thus detached from one of the surfaces and adheres to the other. The transfer can occur from a hard metal to a soft one as well as conversely. A convenient method of measuring quantitatively the amount of metal which is transferred at these localized regions of contact during sliding is to make one of the metals artificially radioactive and to measure the amount picked up with a Geiger counter or by an auto-radiographic technique (figure 11).

Metal surfaces exposed to the air are always covered by a film of oxide or adsorbed gas: this may be only a few molecules thick, but it has nevertheless a profound effect on the adhesion and friction. If we remove this film by heating the metals and allowing them to cool in a high vacuum, the friction is increased. If sliding is attempted the area of real contact increases, and the friction may reach an enormous value.

THE ADHESION OF METALS

We see that when two metals are placed together there is strong adhesion at the local regions of contact. It is therefore pertinent to ask why a strong normal adhesion between the surfaces is not observed. If strong adhesions are formed we might expect that the force required to pull the surfaces apart in a normal direction would be comparable with the force with which the surfaces were originally pressed together, but this is not generally observed. The reasons for this are two-fold. First, in sliding there is more chance of breaking up surface-contaminating films, so that the junctions formed during sliding may be stronger than those formed under normal loading. Secondly, the friction is always measured while the normal load is retained. To study adhesion, however, the normal load must be removed before any adhesion measurements can be made. In the course of removing the normal load, the elastic stresses in the material surrounding the junctions will be released, and there will be a slight change in the shape of the interfacial contour (see figure 1). The junctions themselves, being highly worked, will be relatively brittle, and very small tensile displacements will break them. This means that as the normal load is removed, the junctions are pulled apart one by one so that practically none are left when the adhesion measurements are to be made.

If this mechanism is correct, we should expect to find strong adhesion between metals which are soft and ductile and which do not appreciably work-harden under the conditions of the experiment. With these materials, changes in shape due to elastic recovery would be small and the junctions would be sufficiently ductile to take up any movement which occurs when the normal load is removed. J. S. McFarlane and D. Tabor [2] have shown that this is indeed so. If a soft metal such as lead—or, better, indium—is prepared with a clean surface, and a hard clean spherical indenter of some other metal is pressed into the surface, marked adhesion occurs and a strong normal force is needed to pull the surfaces apart. This normal force is as large as the original load (i.e. the coefficient of adhesion is 1), and fragments of the lead or indium are found adhering to the sphere.

G. W. Rowe [3] has recently studied the adhesion in high vacuum of harder metals, such as platinum, nickel, and silver. The experiments show that although the friction of these naked metals is extremely high, the normal adhesion at room temperature is negligibly small. If, however, the temperature of the metals placed in contact is raised to a point at which annealing can occur and is then allowed to fall to room temperature, the adhesion is very strong. Some typical results for platinum surfaces are shown in figure 2. This heat treatment releases the elastic stresses at the metal bridges, and the adhesion becomes apparent. The temperature at which this occurs for a number of metals is given in Table I.

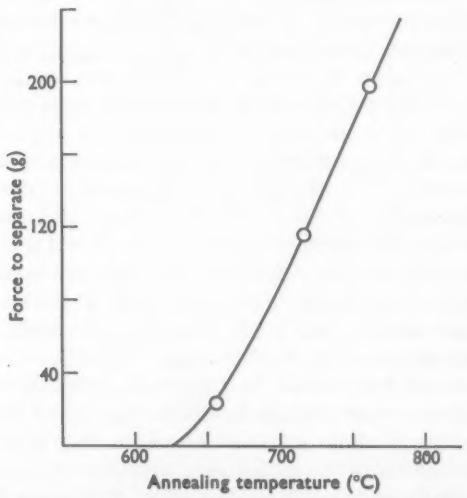


FIGURE 2 – *The onset of adhesion with denuded platinum. Initial load 21 g. Adhesion is observed when annealing releases the elastic stresses.*

TABLE I

Temperature (°C) of onset of normal adhesion for metals in high vacuum

Platinum ..	620	Silver ..	200
Nickel ..	500	Lead ..	*ca* 30
Gold ..	250	Indium ..	< 30

If an attempt is made to slide the clean metals, the combined tangential and normal stresses will cause plastic flow of the contact regions, so that the area of contact, and hence the adhesion, will increase. Adhesion coefficients of well over 10 have been measured at room temperature. This adhesion of clean metals forms the basis of the technological process of cold welding. It is probably of importance also in the initial stages of sintering.

THE FRICTION OF PLASTICS

A study has been made of the frictional behaviour of polymeric materials. The friction of some thermoplastics sliding on themselves is given in Table II.

It is seen that all these materials have coefficients of friction of the same order as those of metals, except P.T.F.E., for which μ is phenomenally low. If a study is made of the surface damage produced during sliding it is found that there is marked adhesion, plucking, and transfer of the plastic from one surface to the other (figures 12(*a*) and 12(*b*)). When plastics slide on metals there is not only transfer of plastic to the metal but also a minute but finite transfer of metal to the plastic (figure 12(*c*)). It is thus possible for a relatively soft plastic to produce slight wear of a much harder metal.

It may again be shown that the friction is dependent on the real area of contact A and the shear strength s of the junctions and may be written $F = As$. Comparison with shear strength experiments on the plastics shows that s is roughly equal to the bulk shear strength of the plastic itself, and the mechanism of friction is essentially the same as for metals.

One major difference between the frictional behaviour of these materials and of metals is the effect of load. With metals the deformation at the regions of contact is truly plastic, and for this reason the real area of contact is directly proportional to the load. With long-chain polymers this is not so. These materials are visco-elastic, and their deformation depends on the geometry of the surfaces, the load W, and the time of loading. In general, the area of contact A follows a relation of the type $A \propto W^n$ where n is less than 1. Consequently the coefficient of friction increases as the load is reduced. This effect can be very marked at light loads, and is particularly evident with polymeric fibres.

Recently M. W. Pascoe and D. Tabor [4] have measured, over a great range of load, the friction and the deformation of polymers and of fibres made from them. A schematic diagram of their apparatus for measuring the friction of fibres *in vacuo* is shown in figure 3. The lower fibre is drawn taut, and supported at both ends on a carriage which can slide along the direction of the fibre axis. It is set up *in vacuo* and driven at low speeds by a synchronous motor. The upper fibre, which acts as a cantilever, can be pressed on to the lower surface by a micrometer screw. With fine fibres normal loads as small as 10^{-6} g can be applied.

The influence of load is very marked; for example, on nylon filament (diameter 0·042 mm) the coefficient of friction μ at a load of 10^{3} g is about 0·4: at a load of 10^{-3} g it is greater than

TABLE II

Polymer	*Common name*	*Chemical formula*	*Coefficient of friction* μ
Polyvinyl chloride	P.V.C.	$(-CH_2-CHCl-)_n$	0·4–0·5
Polystyrene ..	Polystyrene	$(C_8H_8)_n$	0·4–0·5
Polymethyl methacrylate	Perspex	$\left(\begin{matrix}CH_3-C-COOCH_3\\ \|\\ CH_2\end{matrix}\right)_n$	0·4–0·5
Nylon		$(CO-(CH_2)_6-CO-NH-(CH_2)_6-NH-)_n$	0·3
Polyethylene ..	Polythene	$(-CH_2-CH_2-)_n$	0·6–0·8
Polytetrafluoroethylene	P.T.F.E. (Fluon, Teflon)	$(-CF_2-CF_2-)_n$	0·05–0·1

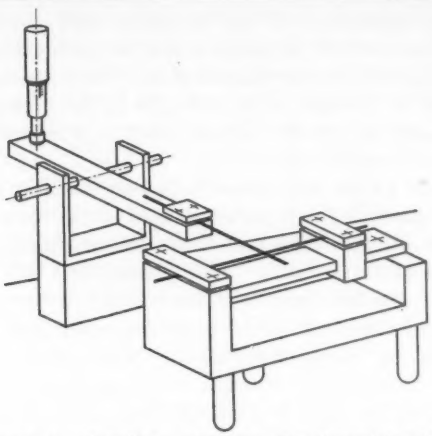


FIGURE 3 – *Cantilever apparatus for determining friction between fibres* in vacuo.

1·2. Tabor's calculations show that this follows the variation in the true area of contact, and is essentially a reflection of the force required to shear the plastic over this area. The fibres are in general covered with minute irregularities, or 'cobblestones', so that the area of true contact may be expected to be appreciably less than the area of deformation. However, at light loads it would appear that contact occurs over only a few asperities—possibly only one. For example, with the 0·042 mm nylon fibre the largest loads used—about 0·1 g—give a circle of contact having a diameter about 0·004 mm, whereas the diameter of individual 'cobblestones' is of the order 0·002 mm. It is not possible to show the contact region at these relatively small loads, but the reflection electron micrograph of a similar fibre at much heavier loads (figure 16) illustrates this point. In this micrograph a flat metal slider was slid over the fibre at a load of 40 g. The width of the track is nearly 0·02 mm, that is, about five times the width of the widest track formed in the crossed-fibre experiments. This supports the view that in the friction measurements on crossed fibres, where the loads are very light, the contact can be considered as being single-point contact. For this reason the area of real contact is very nearly equal to the area of deformation, and the friction follows the same law as the area of deformation itself. On the basis of this simple physical picture, reasonably good frictional correlation is obtained for a load range of 10^{10} to 1 and for surfaces differing in their radius of curvature by a factor of more than 300 to 1. With most plastics the adhesion is strong; shearing takes place at a little distance from the interface, so that transfer and wear occur. With P.T.F.E. the adhesion is small; slip may occur at the interface, and the friction is low. This appears to be an inherent property of the material, since it retains its low friction even in high vacuum, when most of the surface films would be removed. If the surface is subjected to prolonged running at high speeds the frictional heating may damage it and cause a rise in the friction. Its frictional behaviour on snow and ice will be discussed later.

ELASTIC SOLIDS. DIAMOND

The frictional behaviour of diamond is of particular interest because of its great hardness and high elastic constants. It is found that the deformation of diamond is elastic under normal loads and that the conditions at the contact region during the sliding of diamond on diamond are those of elastic deformation. This means that the area of real contact is not proportional to the load W but to $W^{2/3}$. The friction should therefore not be constant: it should decrease as the load increases, and the coefficient of friction μ should be proportional to $W^{-1/3}$. Figure 4, curve I, shows the experimental value for clean diamond exposed to air: the theoretical relationship is obeyed. It

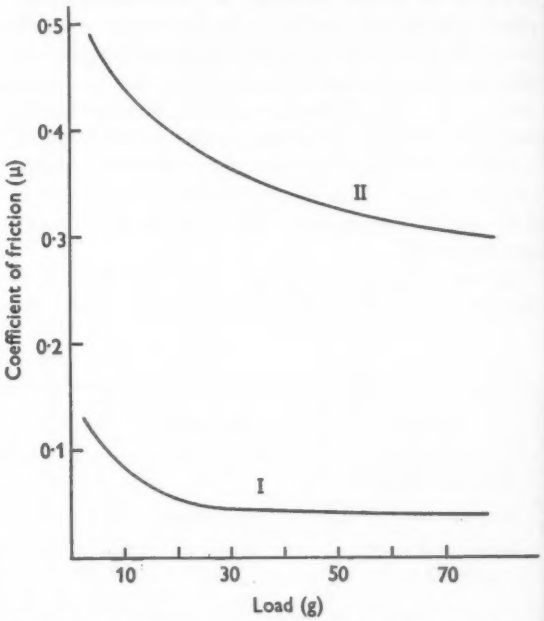


FIGURE 4 – *Friction of diamond as a function of load. Curve I: The coefficient of friction* μ *increases as the load is reduced and follows approximately a law of the type* $\mu = kW^{-1/3}$ *associated with elastic deformation. Curve II:* In vacuo, *when surface films are removed, the friction rises to a high value.*

will also be seen that the friction is small; for a load of 70 g, μ is about 0·05.

Figure 4 also shows another effect. If the adsorbed film of oxygen and other gases which is normally present on the surface is removed by heating the diamond and allowing it to cool *in vacuo*, the friction rises markedly (curve II). This effect of removing gas films is similar to that observed with metals. With metals, however, gross seizure occurs. This does not happen with diamond, simply because diamond is not ductile and junction growth cannot occur. A calculation of the real area of contact, assuming elastic deformation and using Hertz's equation, shows that for a clean diamond sliding on another *in vacuo* the effective shear strength over the region of contact is high and is comparable with the bulk strength of diamond.

There is another interesting feature about the friction of diamond on diamond. The coefficient of friction varies with the crystallographic orientation of the direction of sliding. This effect has been studied by D. M. Kenyon and more recently by M. Seal [11], and some of Seal's results are shown in figure 5. Here the coefficient of friction between a diamond slider and a polished cube (100) diamond face is plotted against the sliding direction on the face. There is evidence of fourfold symmetry in the frictional variations. The maxima occur in the directions of the crystallographic axes. These directional frictional variations add to our understanding of the mechanism of abrasion of diamond. Diamond is normally polished against a rotating iron lap or 'scaife' charged with diamond dust. It has been known for a very long time that there is a marked anisotropy in the abrasion resistance when diamond is polished in this way:

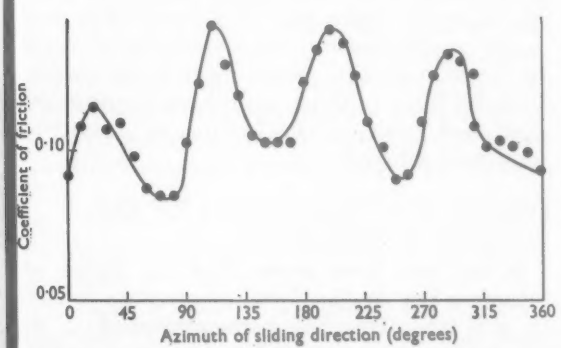


FIGURE 5 – *Friction of diamond is very dependent on the crystallographic direction of sliding. On a cube face it shows a fourfold symmetry. Polishing is easiest in directions of high friction.*

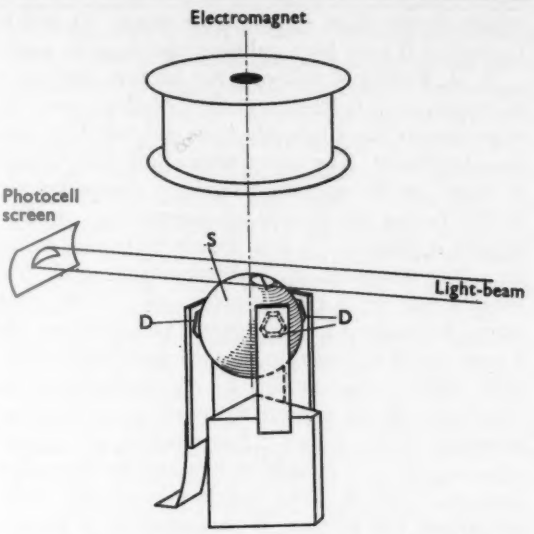


FIGURE 6 – *Method of studying the friction and polishing of diamond at very high speeds. The steel sphere S is suspended magnetically and set in rotation. The friction is measured by its deceleration when the three diamond surfaces D are allowed to rub against it. Rubbing speeds up to* 2000 *miles/hour can readily be achieved.*

the difficult and easy directions differ by a factor of 1000 or more. A correlation has now been established between this abrasive wear and the coefficient of friction. Directions which resist abrasion have a low friction, and those which are more readily abraded or polished have a high friction.

While this observation does not in itself enable one to decide between the various possible abrasion mechanisms, it is consistent with a mechanism for which we have other evidence. This suggests that the attrition of the diamond may be due in part to burning or graphitization at local 'hot-spots'. On a simple theory, the temperature of the 'hot-spots' is directly proportional to the coefficient of friction. The directions of high friction, therefore, have very hot 'hot-spots' and the rate of abrasion is high. It is very difficult indeed to abrade the octahedron (III) face on diamond, and this face shows a low friction in all directions (μ approximately 0·05).

THE FRICTION AND POLISHING OF DIAMOND AT VERY HIGH SPEEDS

The rubbing speed of the 'scaife' used for polishing diamonds varies, but it is seldom higher than about 30 metres/second. Since intense local heating of the surface is an important factor we

might expect that it would be easier to polish diamonds if very high rubbing speeds were used.

E. H. Freitag is studying the friction and wear of metals at very high speeds of sliding, and the experiments have recently been extended to diamond surfaces. The experimental method, which is based on the elegant technique developed by J. W. Beams [5] for his ultracentrifuge, is illustrated in figure 6. A steel sphere is suspended by an electromagnet; it is illuminated, and the shadow falls on a photoelectric cell. If the ball sinks, the current in the magnet will increase. If it rises, it will decrease, so that the ball 'floats'. The ball, which is surrounded by an evacuated glass envelope, can be caused to rotate by a rotating magnetic field. When it has reached an appropriate speed it is allowed to rub against three flat diamond surfaces. The deceleration of the ball, and hence the friction, is measured by a photomultiplier which observes a mark on the top of the ball. With this apparatus it is possible to achieve rubbing speeds greater than 1000 metres/second (2000 miles/hour). Typical results for a steel surface rubbing on diamond are shown in figure 7, curve I. As the speed is increased the coefficient of friction decreases: $\mu = 0{\cdot}02$ at a speed of about 200 metres/second. If the speed further increases, however, there is a sudden increase in the friction, and at a sliding speed of *ca* 250 metres/second the friction rises to $\mu = 0{\cdot}2$. An examination of the diamond surfaces offers an explanation of this. Figure 13 (*left*) shows the diamond surface when the rubbing speed exceeds 250 metres/second: this is a natural diamond surface, and characteristic trigons can be seen. The diamond surface is undamaged, and metal is merely smeared over its surface. The behaviour is consistent with earlier observations that at these very high speeds the high temperature causes softening and melting of the metal to take place on a considerable scale.

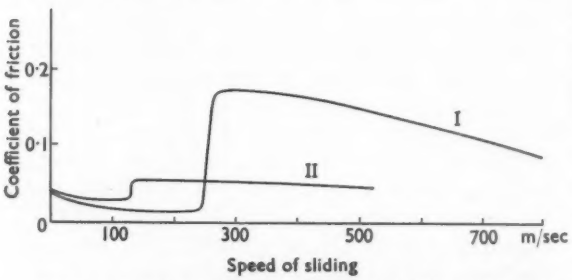


FIGURE 7 – *Curve I: The high-speed friction of steel on diamond. At first the friction decreases with speed, but when this reaches 250 m/second there is a sudden rise in the friction. This is associated with high-temperature softening and melting of the ball and the smearing of metal over the diamond surface (see figure 13 (left)). At speeds just below this the diamond is readily polished (see figure 13 (right)). At still lower speeds no polish occurs. Curve II: Analogous results for copper; the transition occurs at a lower speed because of the lower melting point of copper.*

The change in the diamond surface which is produced by rubbing at speeds just below 250 metres/second is shown in figure 13 (*right*). This is the hard octahedral face of a diamond which is difficult to polish by conventional methods, but nevertheless the steel sphere which has been in contact with it for only a few seconds has polished a crater in its surface. This observation is of some interest, since it shows that if the rubbing speed is sufficiently high, about 250 metres/second, it is possible to polish a diamond without the aid of diamond dust merely by rubbing a metal against it. It is consistent with the view that the polishing and abrasion are due, in an important measure, to the high-temperature burning or graphitization of the diamond. If the rubbing speed is too high, a comparatively large-scale softening of the metal surface occurs, the friction is high, metal is smeared on the surface, and no polishing takes place. If the steel sphere is coated with copper a similar effect, and a similar transition in the friction, are observed (curve II, figure 7), and occur, as we should expect, at a lower speed because the melting point of copper is lower than that of steel. The rubbing speeds which produce polish on the diamond are higher, by an order of magnitude, than the speeds used in the ordinary methods of polishing with a disk impregnated with diamond duct. The surface finish produced on the diamond by rubbing it with steel at an appropriate high speed is a good one. These observations may be of practical interest, since they show that if the speed is sufficiently high very hard solids may readily be abraded or polished by soft ones. It will be shown in the next section that this process may be aided if the surfaces, at the high temperatures developed, react chemically with one another or form solid solutions.

INFLUENCE OF TEMPERATURE ON THE FRICTION OF GRAPHITE

It has long been known that the friction of carbon when in the form of graphite is low ($\mu \simeq 0{\cdot}15$). This has been attributed to its lamellar structure, which allows it to shear readily. Work both in America [6] and in Britain [7] has shown that this is an over-simplification. If the graphite is thoroughly outgassed by heating in a

vacuum the friction rises considerably ($\mu = 0{\cdot}5$) and there is an enormous increase in the rate of wear. Small amounts of oxygen or water vapour can reduce the friction of outgassed graphite to its normal atmospheric value. It would seem, therefore, that the low friction of graphite is due at least in part to the action of these contaminants. Recently Kenyon has measured the friction of graphite sliding on itself and on metals at high temperature and in a high vacuum. With graphite sliding on itself the friction at room temperature is high ($\mu = 0{\cdot}6$), but as the temperature is raised it falls, and at 2000° C it has fallen to $\mu = 0{\cdot}2$. This may be due to a weakening, at the high temperature, of the binding forces between the lamellae. With graphite sliding on copper, silver, or gold similar results are obtained, and the friction falls steadily until the melting point of the metal is reached. With other metals, however, such as iron, nickel, thorium, titanium, molybdenum, tantalum, and tungsten, the behaviour is very different. The initial fall is observed, but at temperatures in the region of 1000° C the friction begins to increase and may reach very high values ($\mu > 2$). Metals which give this large increase in friction are those which are capable of forming carbides or solid solutions with the graphite. When this interaction occurs the area of contact A is increased and the layer at the surface, which may be a metallic carbide, will have a high shear strength, so that the friction may become very great. Copper, silver, and gold do not interact in this way, and they continue to give a low friction even when heated to within a few degrees of their melting point.

THE FRICTION OF WOOD

An interesting attempt to study the frictional behaviour of a more complex solid such as wood is being made by D. Atack. Preliminary results suggest that the frictional resistance to slow-speed sliding of metals on wood is a simple combination of a deformation and an adhesion term. That such a simple mechanism should obtain is at first sight surprising, since wood is a complex biological material, having a highly porous gel structure and exhibiting extensive physical and chemical heterogeneity.

A detailed study of the rolling and sliding of steel and P.T.F.E. spheres on two similar wood species of relatively simple anatomy, Eastern Spruce (*Picea glauca*) and Balsam (*Abies balsamea*), as a function of moisture content has been made. Clean wood specimens were selected and abraded with fine emery under water. Sliding and rolling were conducted across the grain in the spring wood portion of spruce sapwood and balsam heartwood.

Typical results for wood with moisture contents exceeding 30 per cent. are shown in figure 8. It is seen that the sliding friction μ_s is dependent upon ball diameter and load. Tabor [8] has shown recently that the rolling friction of a ball on rubber or on metal is due primarily to an elastic hysteresis loss within the solid. The rolling resistance on wood, which is shown indirectly in figure 8, has been analysed in a similar manner, and the results show that it too is due almost entirely to elastic hysteresis loss in the wood. Lubricants have little or no effect upon the rolling friction values, indicating that interfacial slip or adhesion does not contribute to the resistance to rolling. It seems reasonable to assume, therefore, that

$$\mu_{\text{sliding}} = \mu_{\text{rolling}} + \mu_{\text{adhesion}}$$

The value of μ_{adhesion} calculated in this manner is independent of both ball diameter and load, and may be interpreted in a manner similar to that used for the sliding of metals. A surprising feature is that the curves in figure 8 represent the behaviour for both spruce sapwood and balsam heartwood under equilibrium sliding and rolling conditions. Evidence from similar studies on paper indicates that for both wood and paper the

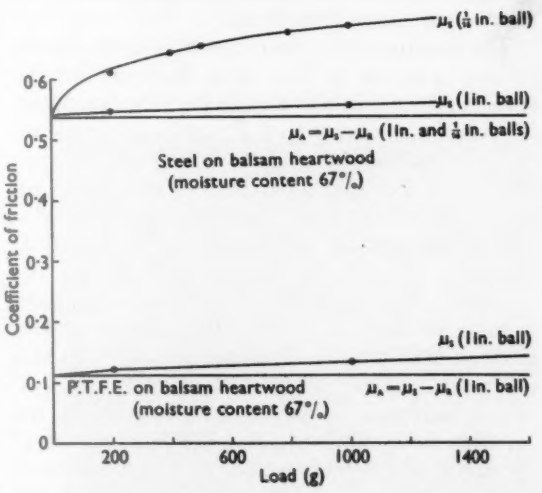


FIGURE 8 – *Sliding friction of wood, μ_s, can be resolved into two components, friction due to elastic hysteresis loss in deforming the wood, μ_R (this is the same as rolling friction), and friction due to adhesion between the surfaces, μ_A. μ_A follows the same laws as the friction of metals and is probably due to hydrogen bonding between the surfaces.*

adhesion is due to hydrogen bonding between unbonded hydroxyl groups in the cellulose and the oxide layer on the steel surface. This would explain the low value of the adhesion term in the case of P.T.F.E. sliders, when such bonding is inhibited. The rolling friction of a P.T.F.E. sphere on wood is almost equal to that of a steel sphere of equal size under otherwise identical conditions. An increasing amount of plastic deformation for rolling and sliding occurs as the moisture content of the wood drops below 30 per cent. This deformation may be calculated approximately in terms of the bulk properties of the wood. Some understanding of the frictional behaviour of wood is important to the paper industry, since wood is disintegrated into its component fibres by frictional methods. It is interesting that so complex a solid may on occasion behave physically in a simple fashion.

ADHESION AND FRICTION OF ICE AND SNOW

The adhesion of ice to aircraft and also to ships sailing in icy seas is still a major problem, and L. E. Raraty has been studying some of the factors which influence this adhesion. His experiments show that if metal surfaces are really free from contaminating grease films the adhesion of ice to all metals is greater than the strength of ice, so that any break must occur in the ice itself. For these reasons, the behaviour is determined by the mechanical properties of ice.

The fracture of ice bears a certain resemblance to that of metals in that under different circumstances either brittle or ductile fracture can occur. Under the conditions of Raraty's experiments, there is evidence that in the temperature range zero to $-6°$ C the failure is ductile. It is influenced by the rate of plastic deformation, and is very dependent on temperature. Below $-6°$ C the failure occurs by brittle fracture and the strength is no longer dependent on temperature. A small amount of contaminant, such as a fatty acid, on the surface will reduce the adhesion to a low value and the failure will occur in the layer of contaminant. If the layer is incomplete, the adhesion is determined primarily by the area of the metal which remains free from contaminant. A small amount of detergent dissolved in the water will appreciably reduce the apparent adhesive strength, but there is evidence that this is due mainly to a reduction in the strength properties of ice.

Raraty has also examined the adhesion of ice to non-metallic solids, particularly to plastics. The general behaviour is analogous to that obtained with metal surfaces, and with some plastics the surface adhesion is again stronger than the cohesion of ice itself. This is not true of all materials, however, and in particular the adhesion to the surface of P.T.F.E. is very small indeed and the break apparently occurs at the interface itself.

Although ice can adhere strongly to appropriate surfaces, the sliding friction on snow and ice is very low ($\mu \simeq 0{\cdot}03$). Osborne Reynolds [9] has suggested that this is due to a water film formed by pressure melting. Our experiments have shown [10], however, that this could be significant only at temperatures very close to zero and with slow-moving surfaces. If the sliding speed is appreciable and the temperatures are below zero, the local surface melting is produced not by pressure melting but by the frictional heating of the sliding surfaces. Table III illustrates the very large drop in friction which occurs when the sliding speed reaches a few metres per second. The results were obtained with variously treated skis. There is evidence that in skiing it is this frictional heating and melting which is the major factor responsible for the low friction.

TABLE III

Influence of speed on friction on ice at $-10°$ *C*

Ski surface	*Coefficient of friction* (μ)		
	Static	*At 3 cm/s*	*At 5 m/s*
Waxed wood ..	0·20	0·18	*ca* 0·02
Lacquered wood ..	0·40	0·36	*ca* 0·03
Perspex	0·35	0·32	*ca* 0·03
Aluminium ..	0·38	0·34	*ca* 0·04

For the past several years I have been combining science with pleasure by investigating in the Alps the mechanism of skiing. A study has been made of the behaviour of a variety of solids, including some new plastic materials, when sliding on ice and snow [10]. Very cold snow behaves like any other crystalline solid, and the results support the early conclusion that the low friction is due to a localized surface melting produced by the frictional heating of the sliding ski. There is evidence that the frictional behaviour is influenced by the contact angle which the water film makes with the surface. P.T.F.E. has interesting possibilities, partly because of its inherently low friction

The
ained
cs the
cohe-
erials,
o the
nd the
elf.
priate
is very
s sug-
ed by
shown
t only
slow-
eciable
local
melt-
sliding
e drop
speed
ts were
here is
heating
onsible

° C

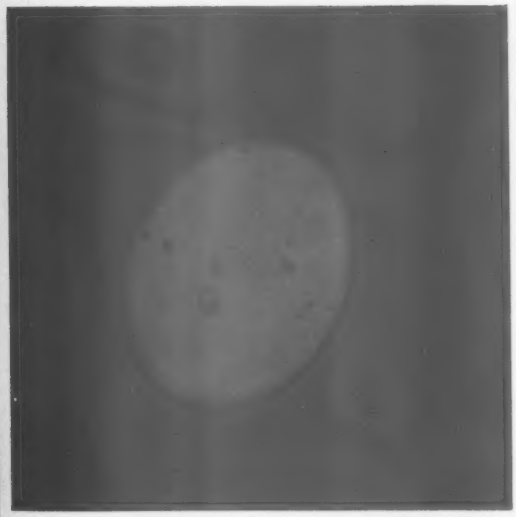
)

5 m/s

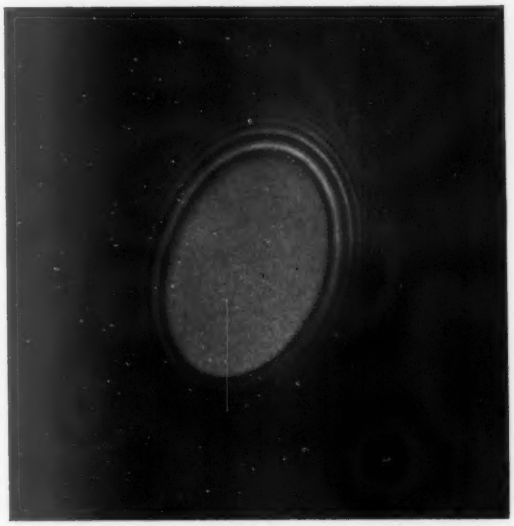
a 0·02
a 0·03
a 0·03
a 0·04

n com-
ating in
udy has
f solids,
n sliding
behaves
e results
friction
uced by
There is
fluenced
n makes
ng possi-
friction

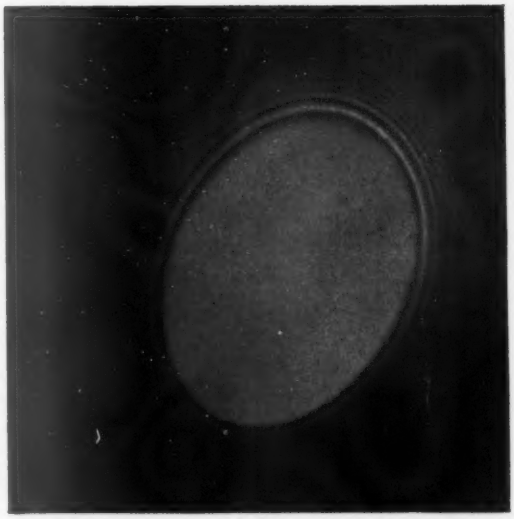
FIGURE 9 – *Multiple-beam interference of cleaved sheet of mica. The regions of uniform colour are molecularly smooth, and the boundaries represent an abrupt change in thickness.* (× 15)



(a)



(b)



(c)

FIGURE 10 – (a) *Region of contact between molecularly smooth mica surfaces. Contact is imperfect because of small particles of contamination. A separation of only a few Ångströms can be detected.* (b) *The same. The surfaces are in molecular contact over the whole region of uniform colour. The colour fringes at the edge are formed where the sheets separate.* (c) *Similar to* (b) *except that the load on the sheets has been increased so that the area of molecular contact is larger.* (× 15)

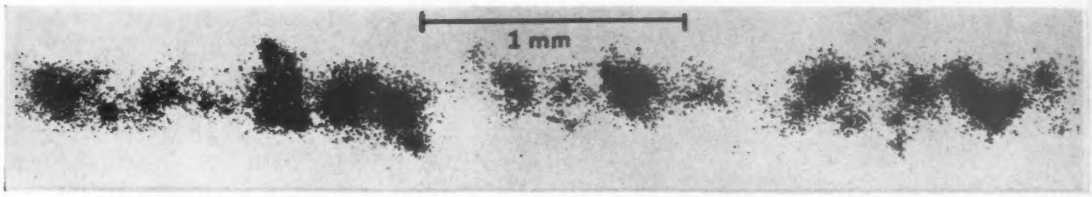
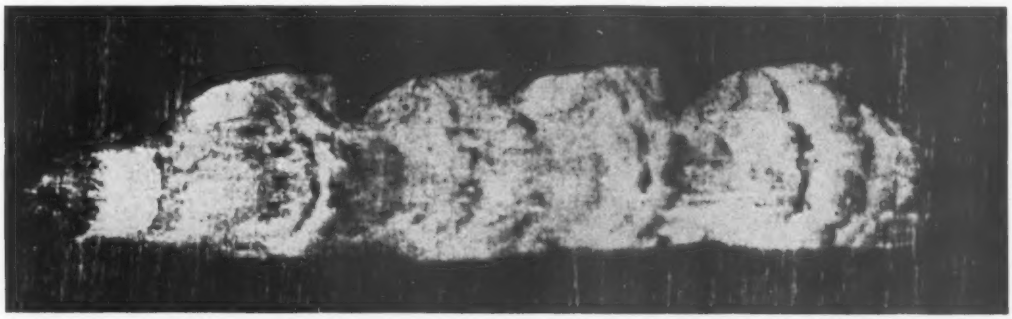
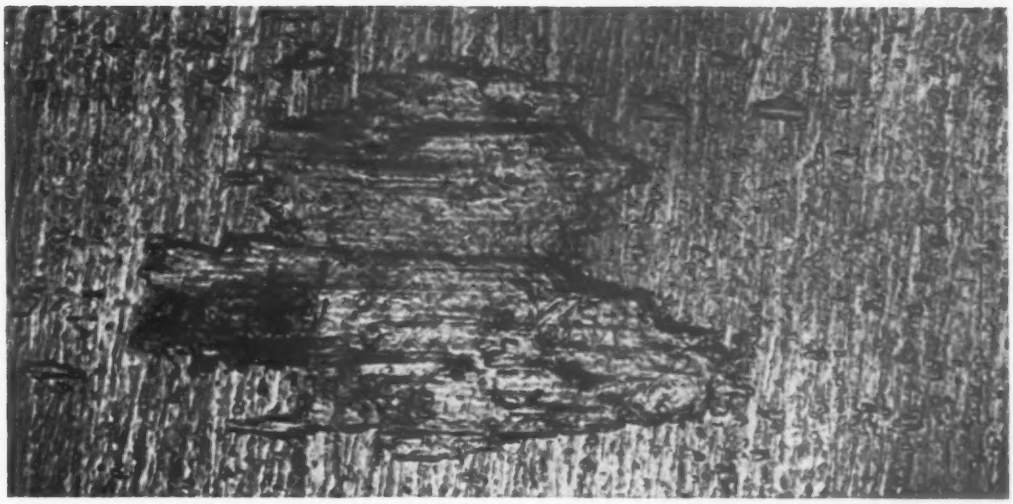


FIGURE 11 – *Autoradiograph of copper transferred to clean steel surface when sliding at a speed of* 0·01 *cm/second under a load of* 2 *kg. The pick-up consists of small fragments and corresponds to about* 10^{-6} *g/cm of track.*

(a)



(b)



(c)

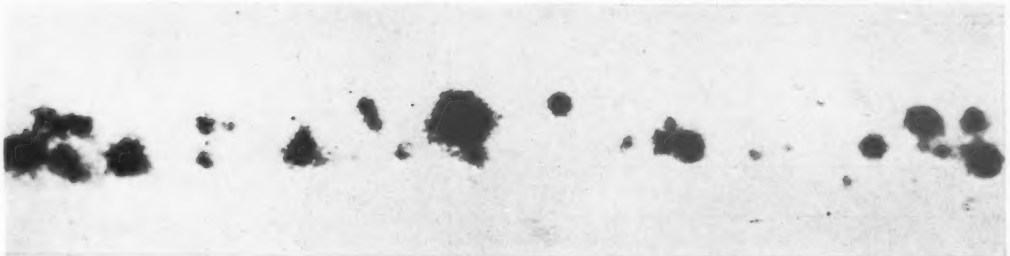


FIGURE 12 – (a) *Track formed when polyvinyl chloride slides on itself. Mutual welding occurs* (× 60). (b) *Track formed when polyvinyl chloride slides on steel. The plastic is welded on to the steel* (× 400). (c) *Track formed when radioactive silver slides on polyvinyl chloride. Some metal* (ca 3 × 10^{-8} *g/cm of track*) *is transferred to the plastic.* (× 20)

FIGURE 13 – (*Left*) *Diamond rubbed at speeds greater than* 250 *m/sec. The diamond surface is undamaged and steel is smeared over it. The triangles* (*trigons*) *are a characteristic feature of the natural diamond face* (× 170). (*Right*) *Diamond rubbed by steel at speeds just below* 250 *m/sec. The diamond surface is readily polished.* (× 200)

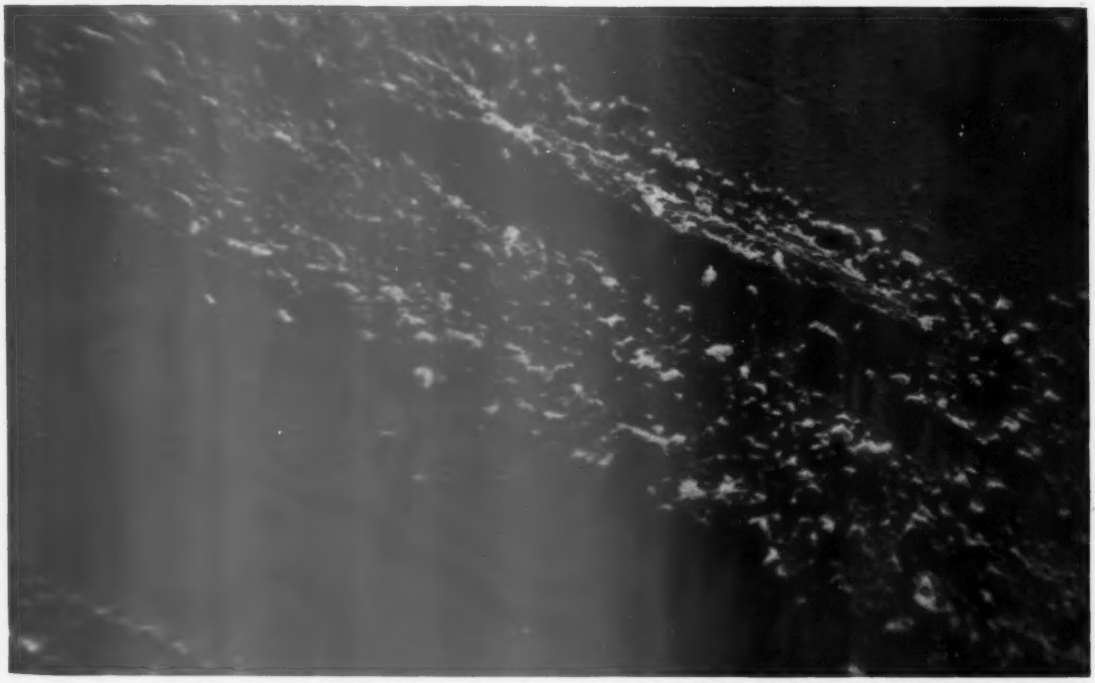


FIGURE 14 – *Reflection electron micrograph of damage when molecularly smooth mica surfaces are placed in contact and slid.* (× 4000)

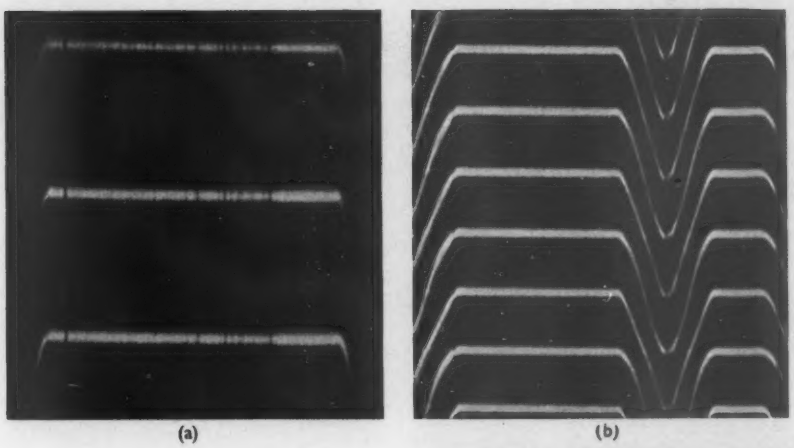


FIGURE 15 – *Fringes of equal chromatic order used in the examination of the area of contact of mica surfaces.* (a) *When the surfaces are in molecular contact, the fringes are each of constant wavelength and flat.* (b) *The presence of a small irregularity is revealed by the deflection of the fringes (shown by arrow).*

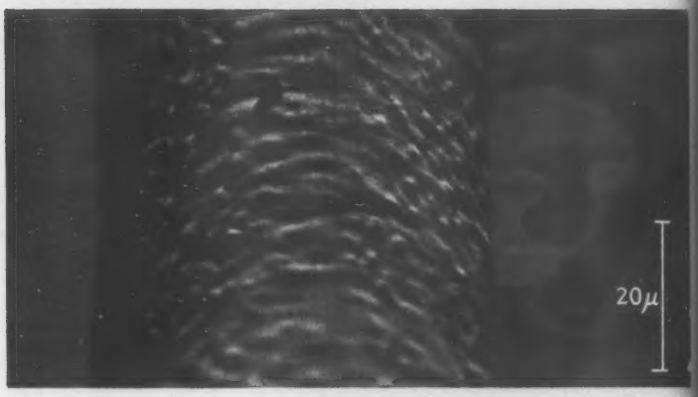


FIGURE 16 – *Reflection electron micrograph of nylon fibre (diameter 50 μ). The curvature of the 'cobblestones' is accentuated by the glancing incidence of the electron beam. Surface damage due to sliding can be seen.*

and partly because of its high contact angle, in consequence of which it is not wetted by water: we may also expect that any hydrogen bonding of the water or the ice to the surface would be difficult. Experiments showed that it did in fact give a low friction under most conditions of sliding on snow and ice. The static friction at various temperatures of skis coated with a conventional ski lacquer, with a racing ski wax, and with P.T.F.E. is illustrated in figure 17. It will be seen that the friction for all these surfaces falls as the snow warms up and also that P.T.F.E. gives the lowest friction. Timed descents have also been made both with live skiers and with dead weights on the skis. Some typical results are given in Table IV.

Under all the conditions of our experiments the P.T.F.E. skis were appreciably faster. They are pleasant and easy to ski on because they give a low uniform friction, even when running on patchy snow. They should have useful applications not only in skiing but also in sledging and in aircraft landing, particularly on very cold or very wet snow. They have been used recently with some success in the Antarctic for the landing and take-off of aircraft on difficult snow.

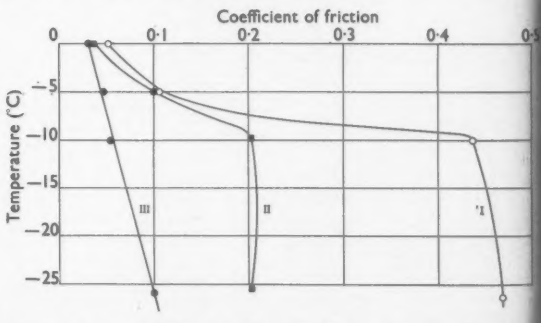


FIGURE 17 – *Influence of snow temperature on the static friction of skis. Curve I: Ski lacquer. Curve II: Ski wax. Curve III: P.T.F.E. The friction is high at low temperatures and falls as the temperature approaches zero. P.T.F.E. gives a low friction at all temperatures.*

1957

of equal
e exam-
ntact of
the sur-
contact,
onstant
b) The
gularity
ction of
row).

0μ

ircraft
ry wet
a some
d take-

0·5

he stati
Ski wax.
tempera-
P.T.F.E.

FRICTION AND ADHESION OF MOLECULARLY FLAT SURFACES

The conventional laws of friction are obeyed because the surfaces are never smooth, so that contact occurs only in local regions. If we could put molecularly smooth surfaces together the behaviour should be quite different. Recently A. I. Bailey and J. S. Courtney-Pratt [12] have been doing experiments of this kind. If good-quality muscovite mica is cleaved with great care the cleavage will often pass along a single plane in the crystal, so that it is possible to obtain sheets which, over an appreciable area, are molecularly smooth on both sides. The great difficulty in these experiments is to be certain that the surfaces are smooth and that over the region where they touch the contact is truly molecular. A minute particle of dust or a cleavage step on the mica which might only be 10 Å high would vitiate the experiment. S. Tolansky [13] has shown that multiple-beam interferometry is an elegant and powerful tool which can detect surface irregularities that are only 3 or 4 Å in height. Figure 9 shows a cleaved mica sheet under examination by this method. The different colours correspond to different thicknesses of the sheet, and over each region of uniform colour the surfaces are molecularly flat. In Miss Bailey's experiments molecularly smooth sheets are selected, bent into cylindrical form, and mounted at right angles. The lower sheet is fixed to the stage of a microscope, while the upper is held up by four equal springs. A highly reflecting layer of silver is deposited on the top surface of the upper sheet and on the under surface of the lower sheet in order that multiple reflections should occur within the two sheets. The apparatus is designed so that normal and tangential forces may be applied and measured.

The contact region is approximately circular, and if the surfaces are within molecular distance the colour of this region will be uniform. In figure 10(*a*) a few minute irregularities of some kind (perhaps tiny dust particles) are present, and the surfaces are not in true contact. Particles or irregularities of this kind, which cause a separation of only a few Ångströms, are easily detected. In figure 10(*b*) the contact is molecular over the whole region. If the load on the mica sheets is increased, this area of contact becomes larger, and this is illustrated in figure 10(*c*).

The contact region may also be examined using fringes of equal chromatic order. This method, which is illustrated in figure 15, has the advantage that the absolute height of any irregularity can conveniently be measured. When the surfaces are in molecular contact the fringes are each of constant wavelength and appear straight (figure 15(*a*)). The presence of a small irregularity is revealed by the deflection of the fringes (shown by the arrow in figure 15(*b*)).

The adhesion has been studied by measuring the force required to separate these surfaces in a normal direction; in a slightly different experiment the work of separation is measured during the actual cleavage process (figure 18). The forces *F* are applied, as shown, to the ends of a piece of mica, causing it to cleave. The ends are held horizontally for experimental convenience.

TABLE IV

Timed descents: Comparison of waxed ski with 'new' ski (P.T.F.E.)

Series 1. Crystalline spring snow; air temperature 5° C; snow temperature zero; gentle slope of length 213 metres (tracked)

Weight on ski (lb.)	*Time of descent (seconds)*	
	Conventional ski with Norwegian wax and paraffin	*'New' ski (P.T.F.E.)*
168	61	42
140	83	54

Series 2. New snow fallen few hours previously; air temperature 10° C; snow temperature zero; unloaded ski (tracked)

Details of slope	*Time of descent (seconds)*	
	Conventional ski with ski lacquer	*'New' ski (P.T.F.E.)*
Gentle, 20 metres long	10	6
Steeper, 30 metres long	6	3

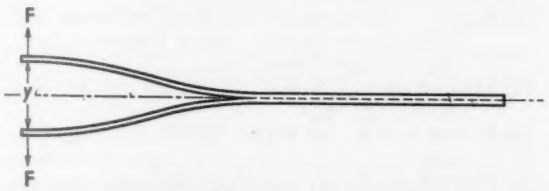


FIGURE 18 – *Method of measuring the work required to separate molecularly smooth mica surfaces. Forces F applied at the ends cause the mica to open by an amount which is determined by recording the movement of the line of bifurcation and the separation.*

The force F and the distance y are measured at intervals as the cleavage proceeds. The corresponding positions of the line of bifurcation are recorded simultaneously, using the multiple-beam interference techniques. From the values of F and y the total work done in the process may be determined.

On first cleaving the mica the energy required is 300 ergs/cm². If the two pieces are allowed to come again into molecular contact and cleaved a second time, it is found that the mica is almost as strong as it was originally, the work necessary being 250 ergs/cm². This result is surprising, since one might expect that contact with the atmosphere would have resulted in the adsorption of gases and water vapour, with consequent loss in strength.

If the sheets are separated and a monomolecular layer of a fluorinated fatty acid is deposited on each, the sheets will still adhere when placed in contact. The work required to separate these layers may then be determined. As we would expect, the result yields a lower value, 155 ergs/cm². These values are estimates of the surface energy of the materials, since they determine the work necessary to create unit area of solid-air interface.

Using the apparatus incorporating the crossed cylinders, the force to shear the junction—i.e. the friction—can also be measured. Such experiments yielded the very high value of 10 kg/mm² for the shear strength of freshly cleaved mica surfaces in contact. The damage to the mica surface under these conditions is very great (see figure 14). Similar observations were made using sheets of mica on which a monomolecular film of the boundary lubricant had been deposited. The material used was calcium stearate deposited by the Langmuir-Blodgett technique, a monomolecular layer being placed on each sheet. The shear strength obtained was then 250 g/mm², and the surface was undamaged. This result is useful in that it shows that when ordinary solids, lubricated with a boundary film, are slid one over the other, a considerable force is necessary to shear the film of boundary lubricant itself.

CONCLUSION

It is evident that there is a close connection between friction and adhesion. Friction is essentially the shear strength, and adhesion the tensile strength of the junctions formed at the region of contact. For most solids, whether they are plastic, brittle, or elastic, the surface adhesion can be strong. The differences in the frictional behaviour of various solids are due mainly to the difference in their mechanical properties, since it is this which determines both the area of real contact and the shear strength of the junction.

Materials which give a high coefficient of friction will potentially give a strong adhesion. Whether this adhesion will in fact be observed depends primarily on the effect of elastic stresses released when the load is removed. If these stresses can be avoided, or if their effects can be accommodated by the ductility of the junctions, the potential adhesion will be observed. If they cannot be eliminated, the observed adhesion may be very small indeed. Lubricants which reduce the friction by diminishing the amount of metallic contact produce an even greater reduction in the adhesion. Similar considerations are important in the action of practical adhesives.

ACKNOWLEDGMENT

This article is mainly an account of recent work by my colleagues and myself. I wish to thank Dr D. Atack, Dr A. I. Bailey, Dr D. M. Kenyon, Dr L. E. Raraty, and Mr M. Seal for assistance in preparing it and for permission to quote unpublished work. An account of background work, with appropriate acknowledgments, will be found in [1].

REFERENCES

[1] BOWDEN, F. P. and TABOR, D. 'The Friction and Lubrication of Solids'. Oxford University Press, 1950. Revised edition, 1954.
[2] MCFARLANE, J. S. and TABOR, D. *Proc. roy. Soc.*, *A*, **202**, 244, 1950.
[3] BOWDEN, F. P. and ROWE, G. W. *Ibid.*, **233**, 429, 1956.
[4] PASCOE, M. W. and TABOR, D. *Ibid.*, **235**, 210, 1956.
[5] BEAMS, J. W. *J. Acad. Sci., Wash.*, **37**, 221, 1947.
[6] SAVAGE, R. H. *J. appl. Phys.*, **19**, 654, 1948.
[7] BOWDEN, F. P. and YOUNG, J. E. *Proc. roy. Soc.*, *A*, **208**, 444, 1951.
[8] TABOR, D. *Ibid.*, **229**, 198, 1955.
[9] REYNOLDS, OSBORNE. 'Mechanical and Physical Subjects'. Cambridge University Press, Cambridge. 1901.
[10] BOWDEN, F. P. and HUGHES, T. P. *Proc. roy. Soc.*, *A*, **172**, 280, 1939.
[11] BOWDEN, F. P. *Ibid.*, **217**, 462, 1953.
[12] BAILEY, A. I. and COURTNEY-PRATT, J. S. *Ibid.*, **227**, 500, 1955.
[13] TOLANSKY, S. 'Multiple Beam Interferometry'. Oxford University Press, London. 1948.

Animal photosensitivity, with special reference to eyeless forms

N. MILLOTT

Many eyeless animals can respond to light in a variety of ways. Often the general body surface is sensitive to light, but the precise structures concerned in absorbing it, and the way in which they act, are unknown. The same kind of sensitivity may be present in animals with eyes. There are indications that the mechanism of reception is fundamentally similar to that of eyes, and the organization of the sensory system may become surprisingly complex.

Sensitivity to light is a common property of living matter. Though radiation of wavelength shorter than 3900 Å has profound effects on protoplasm, it plays no part in what are arbitrarily regarded as visual processes, and its effects are consequently beyond the scope of this account, which is concerned with the reception of waves in the range 3900–7600 Å. Most animals possess complex eyes for photoreception; these eyes have a highly differentiated receptive surface or retina, often associated with a lens system for concentrating and focusing the light. Eyes, however, are not the sole means of photoreception. Not only are simpler equivalents, the so-called 'eye-spots', often involved, but the general body surface may be sensitive to a remarkable degree, and it is this form of light perception which is our special concern here.

Little is known of the visual processes of animals other than vertebrates, a few arthropods, and squids. Consequently we have little idea of the evolution of vision. Again, our knowledge of how a complex eye works remains very incomplete, and since there are indications that the process of photoreception depends on a pattern of activity that is fundamentally the same over a wide range of animal forms, the quest for a common denominator may yield important information.

This common pattern consists of the following processes: (1) The absorption of quanta of light energy, which raises the energy level of the capturing molecules. This has been termed primary photoreception, and it occurs in the photoreceptor. Because visible light is absorbed, an appropriate pigment must be present, and this determines the relative sensitivity of the animal to various regions of the spectrum. Photoreceptive areas have often been recognized by virtue of this pigmentation. (2) The excitation of some mechanism coupled to the last, by means of which electrical changes are produced, possibly by a rapid rearrangement of reactive chemical groups, resulting in ionic movements. (3) The transfer of excitation along specialized conducting channels (in cellular animals, the nerves).

Excitation is conducted to an 'effector', either directly, or via analysing, correlating, integrating, and controlling nerve centres, so that the animal becomes aware of light or reacts to it. The reaction, though a terminal event, is an indicator of the effect of light, and unless special analysing methods are used it is the only one available.

In the simplest protozoans neither specially differentiated light-absorbing structures nor specifically involved pigments have yet been identified. In others, even at this level of non-cellular organization, there is a tendency for the photoreceptive area to become localized as eye-spots, sometimes involving dioptric apparatus. There is still some doubt as to whether the light absorbed by the eye-spot pigment is directly concerned in excitation, or whether the pigment acts as a light filter for the real receptive area, which is ill defined. Since in many cases the colour of the eye-spot implies absorption of light of the same wavelengths as are found to be effective in exciting the animal, some workers have held that the eye-spot is in itself the photoreceptor; others maintain that it merely increases the uniformity and rapidity of the responses to light. It is most significant that carotenoids, possibly combined with protein, are present in the eye-spot (p. 27).

The effect of light may be direct and local, causing changes in the thickness and elasticity of the plasmagel and affecting the rate of its change into plasmasol, thereby affecting movement. Alternatively, it may affect the speed and direction of movement by modifying the action of locomotor organelles, so that co-ordination and the

conduction of excitation are involved, though little is known of any special apparatus for the purpose or of how it functions. Responses may be shown to light of unchanging direction or to changes in intensity. Some animals (e.g. *Stentor*) respond to increases, others to decreases, and still others to both (e.g. *Volvox*).

In the vast array of cellular animals tendencies seen in the Protozoa appear again and may be carried further. Localization and specialization of photoreceptive areas result in highly complex eyes, but the direct local effects of light and the general diffuse sensitivity persist to a surprising degree even in relatively highly evolved forms, such as amphibians. Light acts directly and locally in some chromatophores. Diffuse sensitivity appears as the dermal light sense or dermatoptic sense. This appears in almost all phyla, and the early work has been reviewed by W. A. Nagel [1].

The character of the response to light varies greatly. It may be localized and isolated, or general and integrated, involving the whole animal. In the latter category are included the withdrawal reactions of such forms as hydroid polyps, sea anemones, tubicolous worms, and sea cucumbers. Photokinesis (locomotion in a variable direction with respect to the light source) is seen in lampreys, hagfishes, and blinded catfish. Phototaxis (locomotion in a constant direction with respect to the light source) is seen in brotulid and cave-dwelling fish. Tropistic movements (directed by light) occur in sessile organisms such as hydroids or tubicolous worms.

Responses of individual organs to light have been recorded a great many times. Often they appear to be localized manifestations of the withdrawal reactions mentioned above. Noteworthy instances occur in the molluscs *Pholas* (figure 14) and *Mya*, where there is retraction of the siphon in response to light, and in the tunicate *Ciona* (figure 9), where there is closure of the siphonal apertures; these responses form the basis of S. Hecht's classical studies [2, 3]. It is among echinoderms that such indicator responses appear most strikingly: the myriads of organs endowed with considerable independence—such as spines, pedicellariae and podia—respond individually or in co-ordinated groups. Some of the podial responses of the sea urchin *Lytechinus* are shown in figures 19–21. The responses of the spines of the sea urchins *Centrostephanus* (figure 4) and *Diadema* (figure 2) have been examined in detail by J. von Uexküll [4] and N. Millott [5] respectively. Individual systems may respond to light. For example, reproductive systems may respond by ovarian and testicular activity, ripening of germ cells, and spawning. Gametes may respond to light by tactic movements or by fusing, and primordial germ cells by maturation. Many animals show both integrated and local responses.

The type of response may be related to the kind of stimulus. Kinetic responses result from steady illumination, tactic and tropistic responses from similar but directional light, and there are localized responses to changes in intensity. These may be given to increases of intensity only, for example by the bivalve mollusc *Psammobia* or the feather star *Antedon*; or to decreases, as in sea cucumbers such as *Holothuria*, *Thyone*, or *Synapta*, starfish such as *Asterias* and *Cribrella*, in tubicolous worms such as *Branchiomma* (figure 10), and in bivalves such as *Cardium* and *Pinna*. Responses to both increases and decreases appear in molluscs such as *Chiton* and *Mactra*, as well as in echinoids such as *Diadema* and *Centrostephanus*.

Such indications of photosensitivity are unhappily the only ones available until electrophysiological methods have been applied. With such drastic limitation it is not surprising that there is little reliable evidence of the precise structures, or even areas, concerned in dermal photoreception. Until electrophysiological methods have shown nerve impulses arising from photostimulation of dermal receptors, the demonstration of the dermal light sense cannot be regarded as complete.

Within this confine the most direct demonstrations have been obtained using localized stimulation by means of small light patches. By this method Millott [5] has shown that the entire surface of *Diadema* is light-sensitive, but not uniformly so. D. R. Newth and D. M. Ross, using larger light patches, found a somewhat similar condition in the hagfish. The so-called 'eyes' of *Diadema antillarum* have the appearance of, and behave like, iridophores (figure 15, ir.). The precise status of the eyes in *Diadema setosum* has several times been questioned. Much the same applies to the terminal tentacles of echinoids and organs assumed to be specialized photoreceptors in a variety of animals; thus the pigmented spots previously called ocelli around the siphonal openings of *Ciona* (figure 9) are in fact not light-sensitive. In tube worms and starfish the situation is ambiguous. The ocular spots on the tentacles of the branchial crown of *Branchiomma* are not essential for the animal's most characteristic response to changes in light intensity, and in starfishes the function of the eyes is far from clear. The great majority of investigators

1957

n and
, and
ht by
ordial
show

e kind
steady
from
alized
ay be
ple by
er star
s such
ch as
uch as
ch as
creases
Chiton
iadema

e un-
lectro-
With
g that
struc-
photo-
ls have
imula-
of the
nplete.
onstra-
ulation
nethod
face of
nly so.
r light
in the
illarum
irido-
of the
n ques-
rminal
to be
imals;
ocelli,
ure 9),
ms and
ocular
own of
's most
inten-
es is fa
igator

FIG
adap
and

FIG
due
test,

FIG
tion.

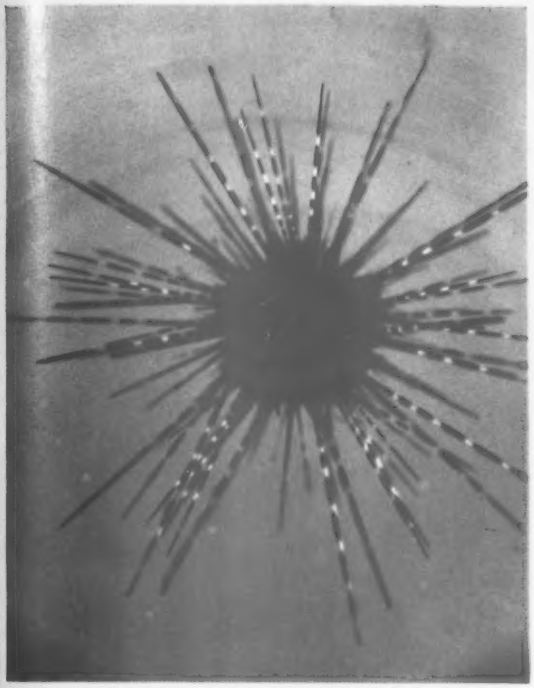


FIGURE 1 – Diadema antillarum. *Young individual in the light-adapted condition when melanin is dispersed over the light-sensitive surface and sensitivity to shadows is diminished.*

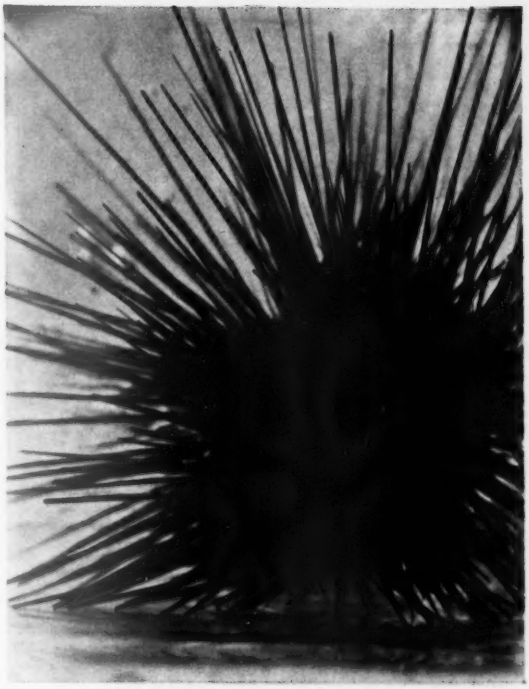


FIGURE 2 – Diadema antillarum. *Adult, showing the spines which are moved vigorously towards shading objects.*

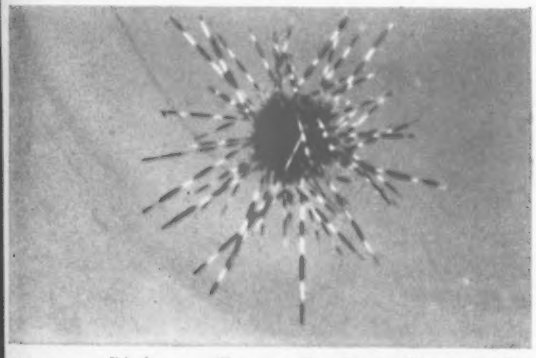


FIGURE 3 – Diadema antillarum. *Here the animal is paler in colour due to concentration of melanin, exposing the light-sensitive surface of the test, so that sensitivity to shadows is increased.*

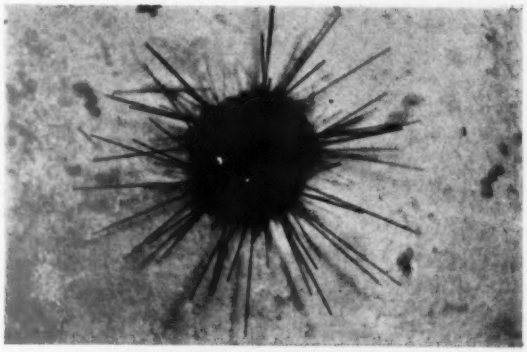
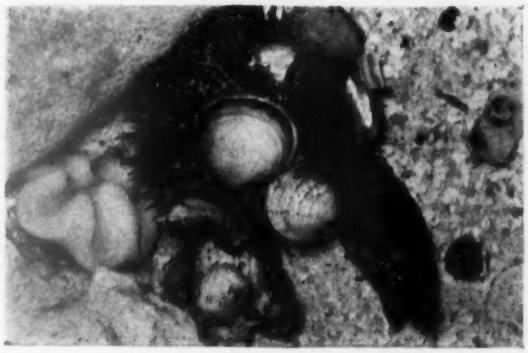
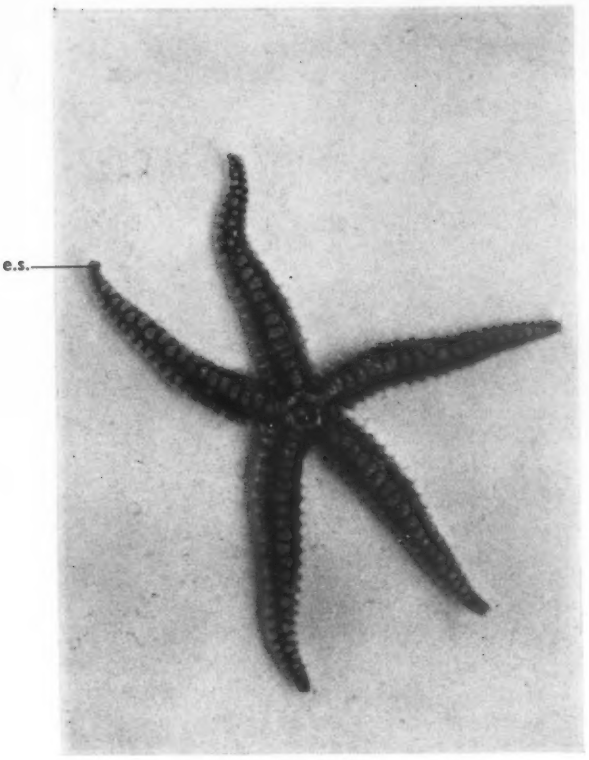


FIGURE 4 – Centrostephanus longispinus, *which also shows well marked spine movements and colour change in response to changes in light intensity. The extensive pigment appears to serve as a light screen.*



FIGURES 5 AND 6 – Lytechinus variegatus, *showing the covering reaction. Figure* 5 *(left) shows the urchin with its covering removed. Figure* 6 *shows the urchin as it usually appears in shallow sunlit waters, covered by debris, including shells of bivalve molluscs, held in position by the podia.*



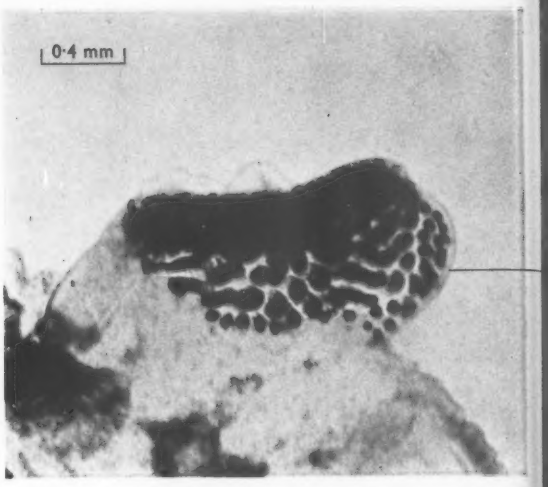


FIGURE 7 – Marthasterias glacialis. *The excised eye-spot (optic cushion), showing the optic cups (o.c.), the prominent colour of which is due to β-carotene and esterified astaxanthin.*

FIGURE 8 – (*Left*) Marthasterias glacialis, *showing the position of the eye-spot (e.s.); one is present at the tip of each arm. Some colour of the body wall is due to the same pigments as those in the eye-spots.*

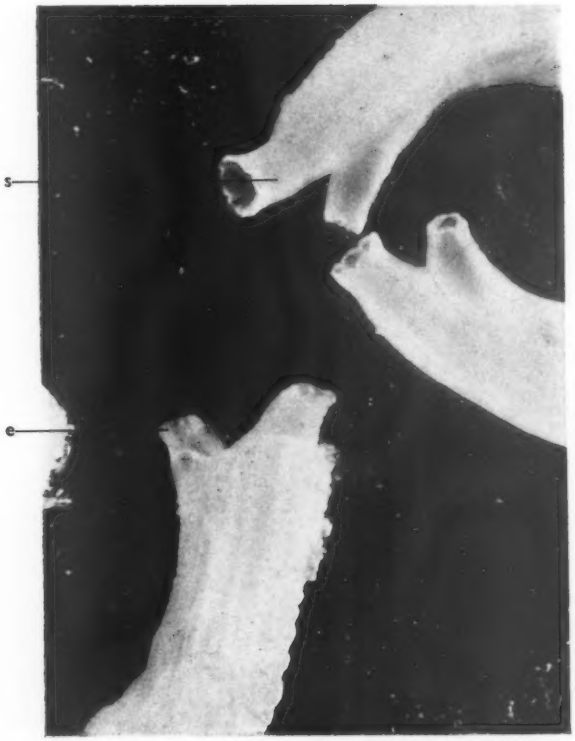


FIGURE 9 – Ciona intestinalis, *which responds to light by retraction of the siphons (s). The so-called ocelli (e) are not sensitive to light.*

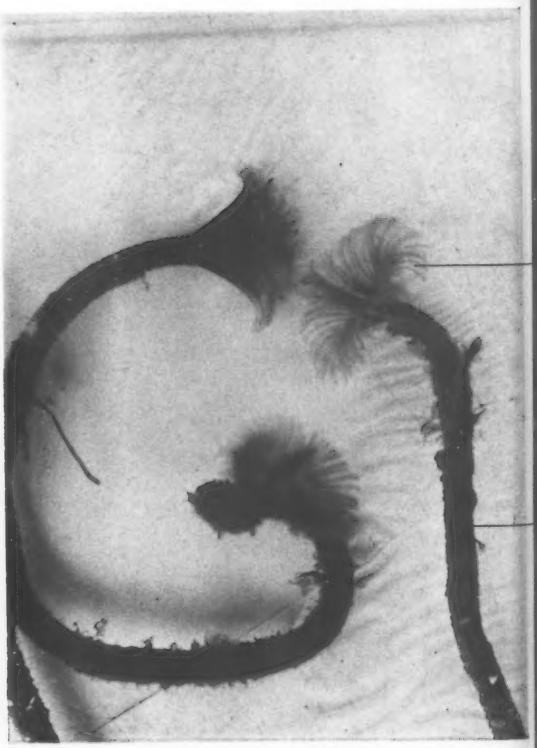


FIGURE 10 – Branchiomma vesiculosum, *which withdraws into its tube (t) in response to shadows, showing the light-sensitive crown of tentacles (c.t.).*

FIGURE 11 – Marthasterias glacialis; *the lower (oral) surface of one arm tip, showing the eye-spot (e.s.), revealed by removing part of the surrounding body wall. p, podia.*

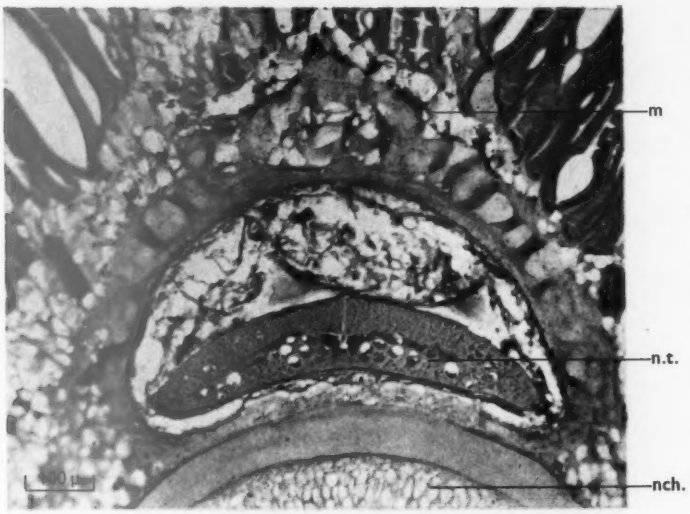


FIGURE 12 – *Part of a transverse section of the ammocoete larva of lamprey, showing the light-absorbing melanin (m) which shields the central nervous system (n.t.). nch., notochord.*

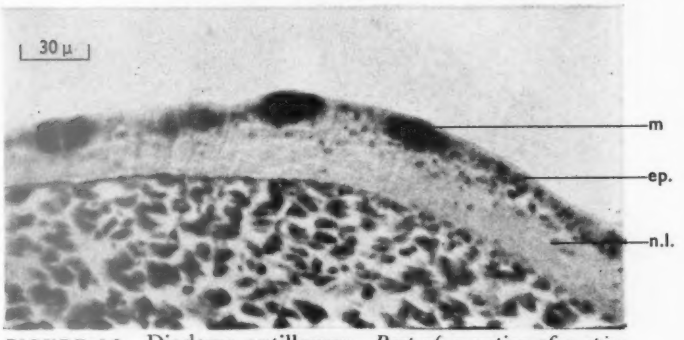


FIGURE 13 – Diadema antillarum. *Part of a section of a spine base, showing the melanophores (m) which shield the superficial nerve layer (n.l.). ep., epidermis.*

FIGURE 14 – Pholas dactylus, *showing the siphon (s) which is retracted when stimulated by changes in light intensity. The entire surface is stated to be light-sensitive.*

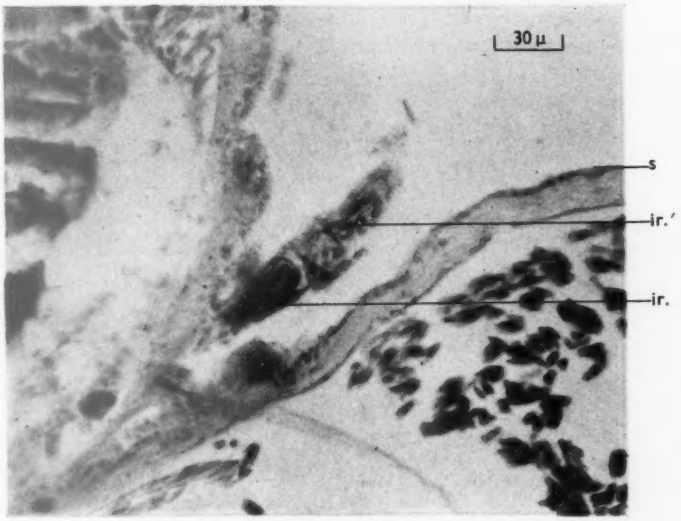


FIGURE 15 – Diadema antillarum. *Section of the region between two spine bases, showing two iridophores (ir. and ir.'). s, epidermis covering outer surface.*

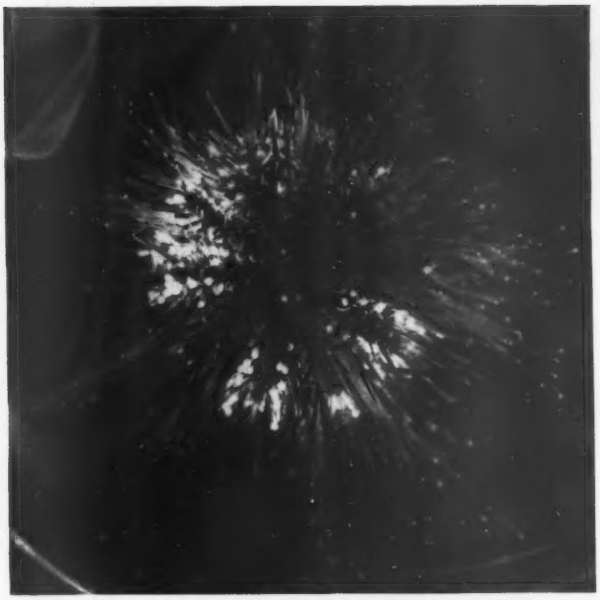


Figure 17

FIGURE 16 – (*Left*) Lytechinus variegatus. *Young individual, sh ing the extended podia which pick up covering from the surrounding hold it so as to shade the aboral surface. The white tips of the podia suckers.*

FIGURES 17 AND 18 – Lytechinus variegatus. *Two stages of covering process. Figure 17 shows two extended podia attached by suckers to a mollusc shell (bottom left). The tips of the sea urchin's sp are seen at top right. Figure 18: A later stage, showing the shell, toge with two similar ones, after being pulled on to the spines by the po Additional tube feet have been applied to the shell.*

Figure 18

Figure 19

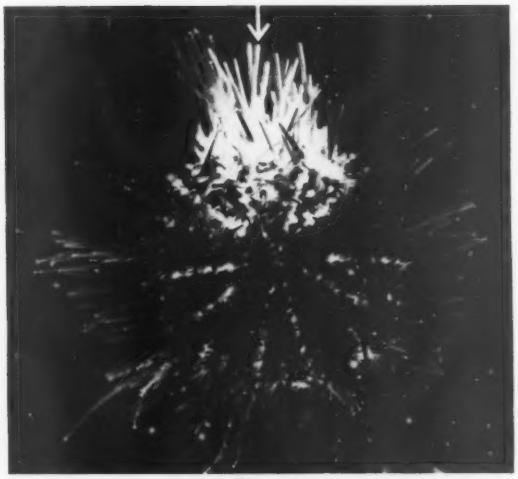


Figure 20

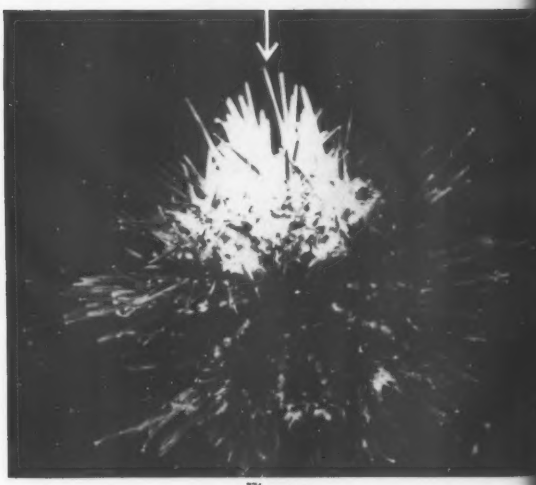


Figure 21

FIGURES 19–21 – Lytechinus variegatus. *Reactions of the podia to light. Figure 19: Extension of the tube feet following a decrease in light intensity. The tube feet in the light beam (directed along the arrow) were photographed while still extending in response to a brief interruption of the beam. Figure 20: Extension of the podia (identifiable by their white terminal suc immediately after transfer from dim light to a steady beam, directed alon arrow. Figure 21: After 10 minutes, the podia in the light beam having to reach covering, are withdrawn, while the remaining podia are still exte*

RY 19

ividual, sh
roundings
the podia

stages of
ached by t
urchin's sp
shell, toge
by the po

minal sut
rected alon
n having
e still exte

agree that the skin of various starfish is light-sensitive, but the eyes (figures 7 and 11) have been described in *Asterias* and *Solaster* as essential for phototactic responses (though for *Asterias forbesi* this has recently been denied), while they are stated to be unnecessary for orientation in *Echinaster* or in *Asterina*. Apart from their function in orientation, the eyes of an unspecified species of *Asterias* have been convincingly shown to be genuine and sensitive to light by the exquisite technique of H. K. Hartline [10], who recorded the electrical impulses in the eye-spot following light stimulation. Here dermal sensitivity co-exists with differentiated eyes, a condition that exists in other forms, particularly insects, where the eyes are much more elaborate.

Apart from the eyes, the photosensitivity of the general body surface may show some differentiation. Thus in various molluscs showing such diffuse sensitivity the mantle edge, tips of the siphons, and pallial gills are most sensitive. In some tubicolous worms sensitivity is confined to the tentacles (figure 10), the distal quarter of which is more sensitive than the rest. In cyclostomes, either anterior or anterior and posterior regions of the body are most sensitive. In fishes the posterior regions are the most sensitive. In the acorn worm *Ptychodera*, as in the earthworm, the anterior tip of the body is most sensitive. In some starfishes an interesting differentiation has been described: the podia and skin gills are stated to be particularly sensitive to steady light, while the body surface is said to be sensitive to changes in intensity. In sea cucumbers such as *Synapta*, on the other hand, the whole surface is sensitive to both. In *Holothuria surinamensis* the whole surface is sensitive to shading, but the rim of the cloaca is particularly sensitive, the posterior end and tentacles are less so, and the podia are the least sensitive.

By attempting to correlate the differential distribution of sensitivity in the body surface with histological structure, efforts have been made to identify the precise structures concerned in photoreception. In earthworms and in the bivalve *Mya* the sensitive regions embody special cells with lens-like organoids which are prolonged into nerve fibres, the whole apparatus appearing to be a photoreceptor. In the skin of lamprey larva, scattered, apparently sensory cells, containing what appears to be a carotenoid protein, have been described by D. Steven. Their wide distribution and pigmentation (see below), together with some features of dark adaptation, suggest that these structures may be involved in photoreception. Crozier has suggested that pigmented cells in the skin of *Holothuria surinamensis* may be photoreceptors. In general, however, localization of sensitivity is too ill defined to be of much use in this way, and in all these cases the necessary proof—the electrophysiological demonstration of photosensitivity—is still clearly needed. While the quest for this vital information continues, it may not be inappropriate to note that many investigators have sought for histologically defined or obviously pigmented structures. Such differentiation is not essential, however; for, setting aside the limiting factor of technique, biochemical organization need not necessarily result in visible histological differentiation. Much the same argument applies to the preoccupation with obvious pigments, for the simpler protozoans react effectively to visible light without obvious pigment, and the masterly biochemical analyses of G. Wald [6] and his associates, together with the similar physiological analyses of R. Granit [7], W. A. H. Rushton, and others, indicate that even in some highly complex eyes little photosensitive pigment is directly required for excitation and, so far as can be seen at the moment, most of it constitutes a store.

The photosensitivity recently described in the echinoid *Diadema* [5] has shown that there is a remarkable correspondence between sensitivity distribution and that of nerve elements, both superficial and deep seated. Although, like the previous findings of J. Z. Young in the lamprey, this does not furnish proof, it clearly suggests that such elements themselves may perhaps be excited directly by light. Such an idea is unorthodox, for it is widely assumed that light perception systems mean the existence of integral, morphologically specialized, photoreceptors. Such a direct effect on nerve does not seem improbable, however, for excitatory processes in photoreceptors, nerve cells, and fibres all have a similar electrical manifestation. Further, it could at once explain the prevalent dermal photosensitivity of echinoids, since in these so much of the nervous system is spread out just below the surface. There is no demonstration of such a property in echinoderm nerves, but there are indications that nervous structures other than specialized photoreceptors are excited by light in other animals; examples are the sixth abdominal ganglion of crayfish and lobsters, the genital ganglion of *Aplysia*, and nerve elements in the brain of lampreys, minnows, and ducks. In the first two instances, electrical activity resulting from the action of light has been recorded.

Indications of a different kind derive from

experiments in which nerves, for example those of frogs and crabs, have been rendered light-sensitive by dyes. These experiments must, however, be interpreted with caution. It may be that they reveal the existence of a potential sensitivity to light in such nerves, which normally may merely lack a suitable light absorber. On the other hand, the eosin dyes used in these experiments have long been known to produce in living matter effects that are essentially destructive. These effects resemble photosensitized oxidations, especially of —SH groups (so-called 'photodynamic action'), and differ fundamentally from normal photosensitized processes in living matter (see H. F. Blum [8]). A study of diffusely photosensitive animals has already opened what may be a new vista on this fundamental problem, for the sea urchin *Lytechinus* (figures 5 and 6), which normally covers itself when in strong sunlight, may be induced to do so in relatively weak light by injections of photodynamic dyes such as eosin Y and rose bengal. As will be clear from figures 17–21, the covering response is complex, involving reactions of the podia to steady, continuous light (figures 20 and 21) and to changes in intensity (figure 19). As a result of these co-ordinated reactions, shells, pieces of debris, etc., are lifted from the immediate surroundings and held like sunshades over the light-sensitive surface. In this case the injected dye photosensitized a normal, complex, and co-ordinated chain of events.

Despite the large number of observations, there have been few serious attempts to analyse, in thermodynamic terms, the mechanisms underlying the dermal light sense. The classical studies made by Hecht [2, 3] on *Ciona* and *Mya* still remain the basis of such analyses. Recently Newth and Ross, and Steven, have analysed the photokinetic reactions in cyclostomes.

Hecht conceived two main processes resulting from the action of light: an initial photochemical process, uninfluenced by temperature and showing some conformity to the reciprocal time-intensity relationships prescribed by the Bunsen-Roscoe law; and a succeeding 'dark' process, conforming to reactions of the thermal type. A study of the relations between the intensity of the applied light and the interval between its application and the beginning of a reaction (reaction time), together with changes in sensitivity undergone in darkness, led him to postulate the following fundamental relationship for a given intensity:

Reaction time = sensitization period + latent period.

The sensitization time is the minimum time for which the animal should be illuminated in order to bring about a reaction.

On a basis of these relationships and their temperature characteristics—together with variation of sensitization time with the reciprocal of the intensity, the ability of the animal to attain sensory equilibrium at any intensity, and the change in reaction time after a period in darkness—he postulated reactions of the following type as the fundamental processes underlying sensitivity to light.

1. A bimolecular photochemical reaction in which a photosensitive substance S decomposes in light, yielding the products P (a precursor of S) and an accessory substance A. P and A recombine to form S in the primary 'dark' reaction:

$$S \underset{\text{Dark}}{\overset{\text{Light}}{\rightleftharpoons}} P + A$$

2. One or both of the substances P and A is assumed to catalyse a secondary 'dark' reaction in which an inert substance L changes into an active substance T, which stimulates the sensory nerve.

Hecht was well aware of many shortcomings in his scheme, which he advanced deliberately in the simplest possible concrete form. Thus he pointed out that reaction (1), though for convenience presented as reversible, is in reality probably more complex and not strictly reversible. In (2) catalysis by the products of photolysis was suggested as one possible means of producing T, but other means were envisaged, including combination of L and a product of photolysis.

The two 'dark' reactions were regarded as consecutive, but Newth and Ross, on the basis of their findings in hagfish, suggest that they are contemporaneous, or overlap. Steven, working on the same animal, noted that the responses to light consist of an initial, sometimes local, response and later of swimming. He accordingly suggested that in hagfish two levels of excitation are involved, and that these are responsible for the double response. Extensive studies by Wald and his associates have revealed the need for much greater elaboration if the scheme is to remain applicable to events in retinae, where the regeneration of the photosensitive substances has been shown by them to be a complex process involving both energy-absorbing and energy-yielding reactions, as well as a light-sensitive isomerizing enzyme.

Crozier suggested that in the sea cucumber,

Holothuria surinamensis, both the products of the photolytic decomposition of a skin pigment, and changes in its concentration brought about by changes in light intensity, stimulate nerves.

Von Uexküll's studies on *Diadema* led him to postulate that the reflex reactions to light and shade were initiated by the decomposition of a photosensitive purple skin pigment into substances which stimulate nerve endings. The nerve pathways, and much of the mechanism involved in reactions to light and shade, were conceived as being different. This scheme involved several highly original concepts for which it is hard to find exact physiological equivalents, and it has never been resurrected.

The reactions to both increases and decreases in intensity recall the 'on' and 'off' responses well known as part of the retinal and optic nerve discharge pattern. In view of this it would not be surprising if the differences between responses to increase and to decrease in light intensity were to prove to be due, at least in part, to correlatory mechanisms in the nervous system.

A cardinal feature of any light-perceiving mechanism is the nature of the absorbing pigment, since its specific absorption is a decisive limiting factor in sensitivity. In consequence the degree of sensitivity in various spectral regions may help in identifying the pigments. Though the pigments present in many kinds of eyes have been identified, we have no direct evidence of the nature of the pigments involved in the dermal light sense. It would appear that identification may prove difficult, as in many cases, judging by the total absence of colour to the human eye, they are present in small amount; again, in some sea urchins (figure 2) they are masked by relatively large quantities of skin pigment such as melanin, which plays no known direct part in vision. It is understandable that many investigators should have sought clues in eyes, in even the simplest of which the pigments are more concentrated. Many eye pigments have been identified, chiefly in vertebrates, but also in some arthropods and in squids. A striking feature is that many are carotenoids. One of them, astaxanthin, is also present in the parts of plants exhibiting phototropism. The close association of these pigments with photosensitivity is clearly indicated by their spectral absorption, which follows closely the spectral sensitivity of the animals in which they occur. A fairly close correspondence between the spectral regions most evocative of indicator responses in some animals perceiving light by means other than eyes, and the regions of the spectrum most strongly absorbed by these known visual pigments, suggests that the same kinds of pigments may be involved. Thus the spectral sensitivity of *Mya*, *Ciona*, *Pholas*, and *Lampetra* has been shown by Steven to be compatible with the absorption of vitamin A derivatives of the rhodopsin-porphyropsin type. It is wise to be cautious in identifying photosensitive systems with particular compounds, for in carotenoid proteins absorption varies with both prosthetic and protein moieties, and, as H. J. A. Dartnall [9] has pointed out, many physical factors must be taken into account in making adequate and valid comparisons between absorption and spectral sensitivity.

Other indications have come from studies of the pigments in the skin and eye-spots of starfishes. Thus in *Marthasterias* (figures 7 and 8) the prominent pigments of both are β-carotene and esterified astaxanthin, but it would be premature to draw definite conclusions from such observations, since the eye-spots of *Marthasterias* have not yet been shown to be photosensitive. Nevertheless, a similar condition exists in *Asterias forbesi*, where both skin and eye-spots contain photosensitive, but as yet unidentified, pigment; as already mentioned, a response to light in the eye-spot of one species of *Asterias* has been demonstrated conclusively by Hartline. The early accounts of what were assumed by von Uexküll to be pigments of the visual purple type in tropical sea urchins can be discounted, for he did not characterize them chemically and the evidence of their participation in light perception is wholly inadequate.

Pigments not directly implicated in vision may play a significant indirect role as shielding and filtering pigments in light-sensitive surfaces, both in eyes and elsewhere. The results obtained by H. F. Blum and D. L. Fox, who studied the spectral sensitivity of the flagellate *Dunaliella*, suggest that such pigments may be present even in Protozoa, and carotenoids such as astaxanthin may function in this way in the complex eyes of crustaceans. Melanins, by virtue of their strong light absorption and the nature of their histological distribution, have often been suspected of acting as a protective shield for light-sensitive structures. Thus in lampreys such pigments in the skin and around the spinal chord (figure 12), as already shown by Young, are effective in shielding the light-sensitive central nervous system and lateral line nerves. The significance of melanin in the dermal light sense of the young forms of *Diadema* where the pigment participates in a colour change has been

shown by Millott [5] (figures 1 and 3). The sensitivity to changes in light intensity, using both locomotion and spine responses as indicators, varies with the degree of dispersion of melanin in the skin. As a result, light-adapted phases (dark in colour, figure 1) and dark-adapted phases (pale in colour, figure 3) can be recognized. The dark-adapted are more sensitive. The melanophores lie (*m*, figure 13) immediately to the outside of the superficial nerve layer (*n.l.*), a position that explains how dispersion and concentration of pigment can seriously influence the intensity of light penetrating the skin. Such controlling mechanisms recall those sometimes attributed to the melanin in the retinas of some crustaceans, insects, and vertebrates, the concentration and dispersion of which form part of the so-called 'photomechanical movements' in these eyes.

Some sea urchins which live in shallow sunlit waters possess no such striking amounts of shielding pigment. One such species, *Lytechinus variegatus* (figure 5), is highly sensitive to light, and covers itself extensively with debris (figure 6), an action which is initiated by relatively strong light. This suggests that in doing so it compensates for lack of screening pigment.

In comparing the general organization of a dermal photoreceptor system, such as that of *Diadema*, with that of a complex vertebrate or arthropod eye, certain parallels appear. The responses to changes in light intensity recall the 'on' and 'off' responses in the optic discharge pattern. In each, the primary photoreceptor mechanism is associated with accessory pigments, the disposition of which can vary so as to alter the amount or pathways of incident light. Further, the melanin in young *Diadema*, as in some eyes, shows a diurnal rhythm of dispersion and concentration. Many complex eyes contain reflecting elements forming a tapetum, apparently for the purpose of reflecting and diffusing light of low intensity over the receptive surface; their counterparts appear in the iridophores of *Diadema* (*ir.*, figure 15) which diffuse light over the general body surface (*s*) and may thereby significantly increase the capacity of the urchin to respond in dim light.

Such complexity of organization is rather surprising and may be a reflection of the importance of the dermal light sense. Where eyes are lacking or inadequate such a sense is sufficient, when steady light forms the stimulus, to ensure that the possessor attains the conditions of illumination best suited to its mode of life: by swimming, as in lampreys; by burrowing, as in hagfish; by withdrawing exposed parts of its body, as in some crayfish and lobsters; or by covering, as in *Lytechinus*. When changes in intensity form the stimulus, the sense is adequate to ensure withdrawal from a stimulus of increased lighting or from shadows that may signal a harmful change, or presence, in the near vicinity. The sense is also sufficient to ensure movement toward shading objects, as may occur in the podial reactions of *Lytechinus* (figure 19) in capturing pieces of covering, or in the defensive spine movements of sea urchins.

The dermal light sense has often been described as primitive, and regarded as a survival of the ancient sentient surface, from which specialized photoreceptors have arisen by concentration and localization. That this has occurred there can be no doubt, but such a view can be interpreted in a dangerously simple fashion, and it should not be overlooked that some stages of such a process have occurred at the protozoan level. It is now also evident that a fairly elaborate organization can be attained without much concentration and localization. This suggests that sensitivity to diffuse light may have been redeveloped at various evolutionary levels. Existing knowledge carries us no further, but its paucity at least serves to emphasize the need for much further investigation.

ACKNOWLEDGMENT

The author acknowledges with thanks permission he has received from the following to reproduce some of the illustrations: Dr G. Bras, University College of the West Indies (figures 1 and 3); Mr G. Underwood, University College of the West Indies (figures 5 and 6); Dr M. J. Wells, *Stazione Zoologica*, Naples (figure 4).

REFERENCES

[1] NAGEL, W. A. 'Der Lichtsinn augenloser Tiere'. Fischer, Jena. 1896.
[2] HECHT, S. *J. gen. Physiol.*, **1**, 545, 1918.
[3] *Idem. Ibid.*, **8**, 291, 1925.
[4] VON UEXKÜLL, J. *Z. Biol.*, **34**, 315, 1897.
[5] MILLOTT, N. *Phil. Trans., B*, **238**, 187, 1954.
[6] WALD, G. *Amer. J. Ophthal.*, **40**, 18, 1955.
[7] GRANIT, R. 'Receptors and Sensory Perception'. Yale. 1955.
[8] BLUM, H. F. 'Photodynamic Action and Diseases Caused by Light'. Reinhold Publishing Corporation, New York. 1941.
[9] DARTNALL, H. J. A. *Brit. med. Bull.*, **9**, 24, 1953.
[10] HARTLINE, H. K., WAGNER, H. G., and MACNICHOL, E. F., Jr. *Cold Spring Harb. Symp. Quant. Biol.*, **17**, 125, 1952.

The early history of the vacuum pump

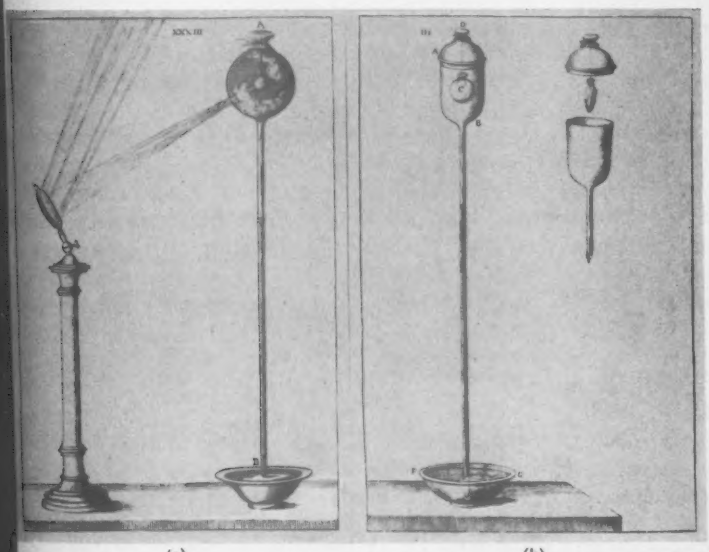
E. N. DA C. ANDRADE

The attainment of a high vacuum is an essential part of many modern processes in research and industry. For the atomic particle accelerators; for the huge atomic plants; for metal refineries; for factories where all forms of electric lamps, valves, television tubes, and such-like are made—for all these, and many others, great vacuum installations are essential. All this, however, is the creation of the last fifty years or so, mainly as a result of the inventive research of Gaede. What is here described is the history of the vacuum pump before these modern developments.

At the beginning of the present century the methods used for producing vacuous space were very much those of a century earlier. In tracing the history of the vacuum pump, then, we have a natural boundary separating the old instrument and plaything of the natural philosopher, with which great discoveries were accomplished, and the modern creation of the physicist-engineer, without which the atomic revolution could not have been effected.

The first man to produce a vacuum deliberately and to realize clearly what he had done was Torricelli, a student of Galileo's. Galileo in the First Day of his *Dialogues* had drawn attention to the fact that a pump could not draw up water through a height greater than 18 braccia (which seems to have been about 1060 cm, a comfortable margin above the limit in fact attainable). He had also established that air had weight, but certainly did not at the time connect the weight of the atmosphere with the height of the water column. Torricelli in 1644 described his famous experiment in a letter to Michel Angelo Ricci. What concerns us here is the development of the Torricellian method to produce a vacuous space for experiment; this was carried out by the *Accademia del Cimento* and published in its *Saggi di Naturali Esperienze* in 1667.

The top of the barometer tube was enlarged, and access to this space was provided by an opening which could be closed by a sheet of bladder, suitably supported. In such a space significant experiments were carried out. It was shown, for instance, that the magnetic force was the same in vacuo as in air; that smoke, produced by heating a small ball of bitumen with sunlight focused by a mirror, fell in vacuo: that a lamb's bladder, squeezed out and tied so as to contain only a little air, swelled out to a sphere in vacuo (figures 1(*a*) and 1(*b*)). This method of producing a vacuum,which was used long after by Rumford, can be considered as the application of a one-stroke mercury pump, and the experiments achieved are distant forerunners of those carried out with the Geissler and Töpler pumps some two hundred years later. They were, of course, subsequent to the invention of the airpump by Guericke and to the earliest airpumps of Boyle, now to be



(a) (b)

FIGURE 1 – *Experiments carried out by the* Accademia del Cimento *with the Torricellian vacuum.* (a) *shows smoke falling in vacuo;* (b) *a lamb's bladder, containing a little air, swelling in vacuo. In both cases the top of the experimental vessel is closed with bladder, but in* (b) *the bladder is carried by a glass lid, to which no reference is made in the text. In the English translation quoted the right hand figure in* (b) *is omitted.*

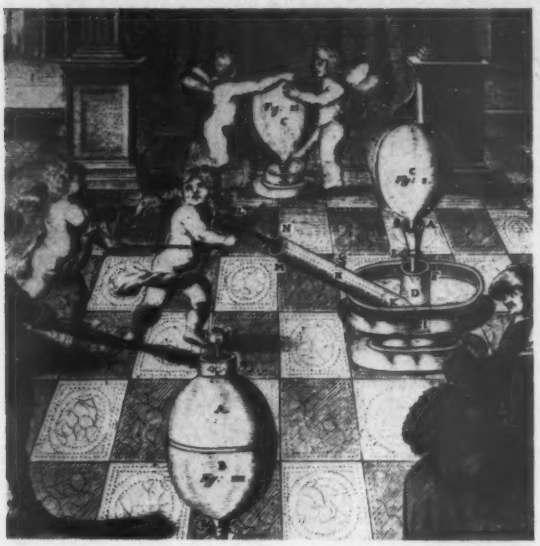


FIGURE 2 – *The first representation of a vacuum pump, from the description of Guericke's early work in Schott's* Mechanica Hydraulico-Pneumatica.

described, but, as is said quite truly in the *Saggi* when Boyle's 'curious and noble Experiments' are cited, '. . . the Vessel can never be emptied so perfectly by that way, as by Mercury.'[1]

It was Guericke, of course, who first produced an airpump in the sense of a machine by which any space could be progressively evacuated to the limit which leaks and vapour pressure imposed. The exact date of his first successful attempt is uncertain. Guericke himself, who was born in November 1602, gave a comprehensive account of all his work in his *Experimenta Nova (ut vocantur) Magdeburgica de Vacuo Spatio* (The New, commonly called Magdeburg, Experiments on Empty Space) in 1672, long after it was carried out. The famous Magdeburg experiment was, however, cited much earlier and the pump described, with Guericke's sanction and approval, by the Jesuit Kaspar Schott, a very active writer on scientific subjects, in his *Mechanica Hydraulico-Pneumatica* (1657), the book which was the first occasion of Robert Boyle's interest in the airpump. The experiment was actually carried out in 1654, in the presence of the Emperor and princes assembled at Magdeburg for the imperial diet at Regensburg.

In this celebrated demonstration two copper 'Magdeburg hemispheres', about 50 cm in diameter,[2] were used, fitted with iron rings to which teams of horses could be attached. They were

[1] Quoted from the translation by Richard Waller, published in 1684.

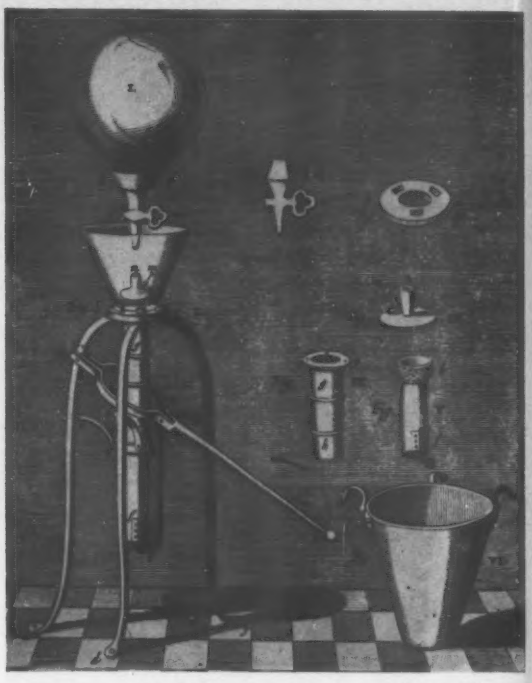


FIGURE 3 – *Guericke's pump, as figured in* De Vacuo Spatio.

placed together so as to form a sphere, the joint being made airtight by means of a leather washer soaked in wax and turpentine. When the enclosed space was exhausted, two teams of eight horses failed to bring them apart: it would require a pull of about 1·5 tons to do so. Guericke also carried out the experiment with hemispheres about 70 cm in diameter.

The airpump figured by Schott is shown in figure 2, which is the first representation of a vacuum pump ever published. It is described as having two valves, one at H, half-way along the sloping barrel of the pump, G being an opening, and the other at the lower end of the barrel, at I.

[2] Guericke says that the hemispheres were three-quarters of a Magdeburg ell in diameter 'or (because the artificers do not make vessels exactly as requested), 67 hundredths of a Magdeburg ell'. As I had some difficulty in finding the length of this ell, I may mention that the value is given in the *Encyclopédie Méthodique*, Section *Commerce* (Vol. III, p. 165, 1784), as 295·6 French lines, there being 144 French lines to the Paris foot, which was 1·066 English feet. This makes the Magdeburg ell 67 cm, so that we can take the diameter of the Magdeburg spheres as roughly 50 cm. All the histories of science consulted by me record the diameter in Magdeburg ells. As only the rough measurement of the spheres is of interest, these details may seem finical unless it is remembered that the ell varied from 114 cm in England to 56 cm in Leipzig, to take familiar ells only.

No detail is given of these valves, but we are told that the one at I opens inwards towards I and is closed towards D—by which is to be understood that it opens when the piston is withdrawn and closes when it is pushed in—while that at H opens outward to the air under internal pressure and closes when the pressure falls. This positioning of the valves is clearly not a very efficient one, and Schott says that the in-and-out motion (*agitatio*) of the piston has to be continued for two, three, or more hours, according to the capacity of the receiver C. The cherubic lab boys in the background have placed an exhausted receiver nose-down in water: Schott records that when the tap was opened the water would shoot in with a great rush and tumult, as if boiling. The tap E could be used to shut off the evacuated vessel. It was, apparently, with such a pump that the Magdeburg experiment was carried out.

The final form of Guericke's pump, as represented in *De Vacuo Spatio*, where it was first described, is shown in figure 3. It bears many resemblances to Boyle's pump, and it is most probable that Guericke had seen Boyle's book, of which a Latin edition appeared in 1661, although he nowhere refers to Boyle. The vertical cylinder *gh* was supported by a tripod: it is shown separately at 'Fig. III'. A lead washer was used at the top to make an airtight fit. The piston, shown at 'Fig. V', was of wood, with a string packing. To let out the air a leather valve *z*, closed by a spring ('Fig. IV'), was provided. This worked during the early stages: when the air pressure became too small to force it open, the hand-operated peg valve *m* was used. The operation of the tap *qr* and the valve *m* was as in Boyle's pump and will be described when this is considered. The conical vessel *xx* at the top of the cylinder and the other one shown at 'Fig. VI', which was hung so as to enclose the lower end of the cylinder, were to contain water for the purpose of rendering the various joints airtight. The receiver was of glass, cemented to the brass attachment which carried the tap.

Boyle first described his airpump in '*New Experiments Physico-Mechanicall Touching the Spring of the Air*', published in 1660. He says here that he had heard of, but had not perused, the book by the industrious Jesuit, Schottus, telling how 'that ingenious Gentleman *Otto Gericke*, Consul of *Magdeburg*, had lately practiced in *Germany* a way of emptying Glass Vessels, by sucking out the Ayr at the mouth of the Vessel, plung'd under water'. The pump, as Boyle freely acknowledges, was

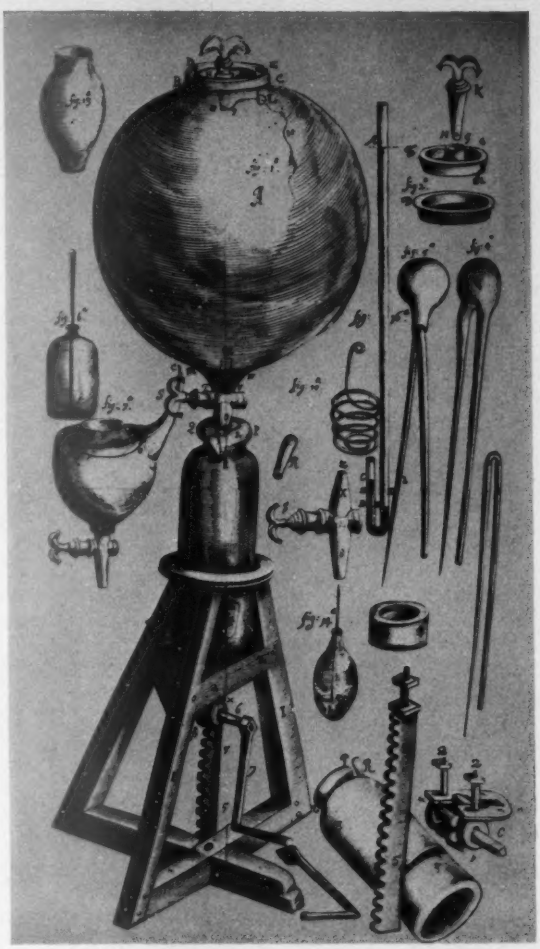


FIGURE 4 – *Boyle's first pump, made by Robert Hooke.*

made by Robert Hooke, employed by him at that time as an assistant, and bears the stamp of his genius in design.

This pump, shown in figure 4, comprised a hollow brass cylinder of about 3 in. internal diameter, in which ran a 'sucker', presumably of wood, since a disk of leather was nailed to it, fitting the cylinder tightly. It is shown as 4, 4, above the detached ratchet. On to this sucker, moved up and down by a rack and pinion, oil was poured to make for easy running and an airtight fit, but Boyle records that a mixture—an emulsion, we should say—of oil and water often proved better. A stout wooden frame held the cylinder vertically. The receiver was a large glass sphere, of some 25 litres capacity, which was, we are told, the largest size that the glass-men could make of the requisite thickness. A great advantage that it

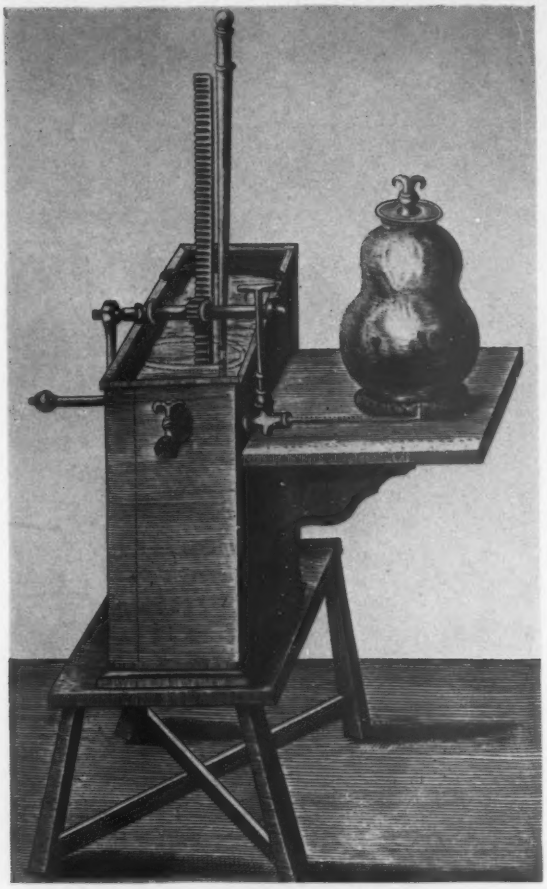


FIGURE 5 – *Boyle's second pump.*

possessed was the opening at the top, into which was cemented a brass ring, adapted to receive the accurately fitting cover shown in detail at the top right-hand corner of the figure. The small hole at the bottom of the plug K was provided for suspending objects in the receiver. This excellently contrived receiver greatly facilitated the carrying out of experiments in vacuo. That Guericke did not adopt it may have been due to inability of his craftsmen to execute it satisfactorily. To the bottom of the receiver was connected a brass fitting, provided with the tap S.

The shoulder of the cylinder was pierced by a hole closed by an accurately fitting brass valve-plug, shown separately at R. The mode of operation was as follows: with the tap closed and the valve-plug withdrawn, the piston was moved to the top of the cylinder, expelling the air through the hole. The hole was then closed with the plug, the piston withdrawn, and the tap opened, so that part of the air in the receiver rushed into the cylinder. The tap was closed, the valve-hole opened by the withdrawal of the plug, and the process repeated. This was the method adopted by Guericke in his last pump, but he added the subsidiary valve, opened by the air-pressure, for the early stage of the pumping. The rack and pinion, the easy access to the receiver, and the general design and execution, which rendered the use of water to seal the joints unnecessary, make Boyle's pump much the superior instrument.

Boyle's second pump, described by him in 1669, is shown in figure 5. The great advantage was that the receiver was a bell-jar cemented to a flat plate by a mixture of beeswax and turpentine, a composition used in vacuum work until well into the present century. It could thus be easily removed and replaced for experimental purposes. The pump was a single cylinder submerged in the water bath shown: the piston itself was pierced by a hole which could be opened and closed by means of a plug on the end of the long stick shown protruding well above the water. The tap is shown on the pipe leading to the bell-jar. Boyle admits that, while having the pump submerged keeps the sucker 'turgid and plump' so that it remains airtight, the arrangement is not without its inconvenience.

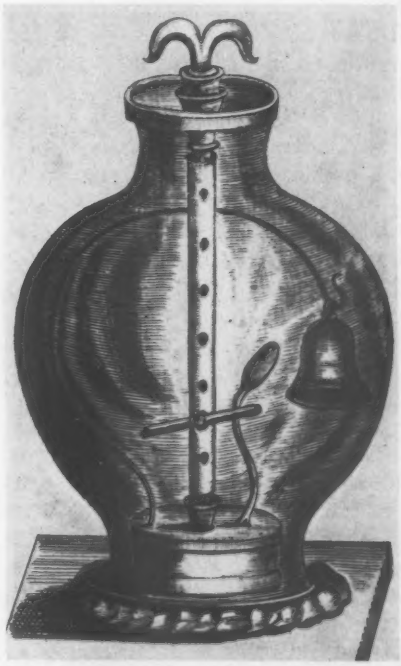


FIGURE 6 – *Boyle's apparatus for showing that sound does not travel* in vacuo.

nto the
ve-hole
nd the
dopted
ded the
ure, for
ck and
nd the
ered the
, make
nt.

n 1669,
vas that
at plate
a com-
into the
emoved
s. The
in the
rced by
y means
protru-
n on the
ts that,
e sucker
ight, the
nce.

sound does

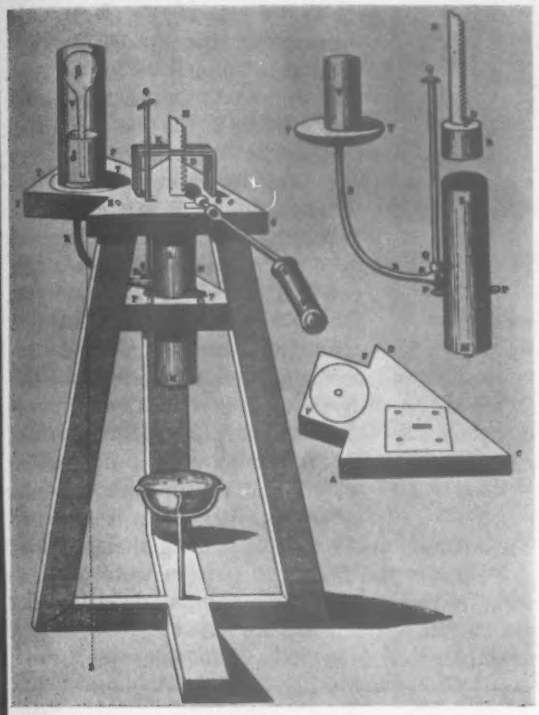


FIGURE 7 – *The pump made by Papin to Huygens' pattern.*

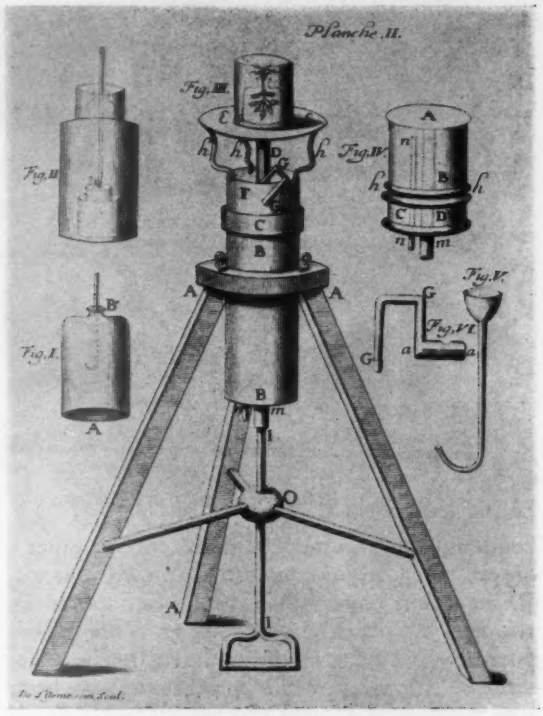


FIGURE 8 – *Papin's pump, with two-way tap.*

It must be remembered that Hooke, who made the first pump, had left the service of Boyle in 1662, and so, presumably, had no part in the making of the second. It is to this that the retrograde step of immersing the pump in water can probably be attributed; it seems likely that, without Hooke's craftsmanship, the airtightness of the piston could not be secured without this submersion. The use of water is the more surprising since, in his account of the first pump, made by Hooke, Boyle says that he wanted a pump 'that might not, like the other [Guericke's], need to be kept under water (which on divers occasions is inconvenient) and might be more easily managed'. This is an early example of the influence of technical accomplishment on design. As typical of the manipulation in vacuo we can take the disposition, whose mode of action is obvious, for striking a bell enclosed in the receiver, shown in figure 6.

Denis Papin, a genius who, like Hooke in his early days, often had to earn his living by assisting other and wealthier men, was in 1674 working with Huygens. The Dutch discoverer had seen Boyle's first pump in England when he was there in 1661 and on his return to Holland had, as we know from his letters, made a pump on the pattern of Boyle's: it had, however, the great advantage of a flat plate, to which a bell-jar was applied to constitute the experimental space. He thus anticipated Boyle in this feature, although he published no account of it. Huygens, in Paris at the time, set Papin to make an airpump of his pattern, which was described in Papin's first publication, *Nouvelles Expériences du Vuide*, 1674. It is represented in figure 7. The piston was worked by a rack and pinion, as in Boyle's pump. One valve was a small hole at M, which was open when the piston descended to expel the air and covered by the finger when it ascended, the connection of the cylinder with the receiver being governed by the tap at F, which was controlled by the handle Q (right-hand detail, figure 7). The piston was made airtight with tow soaked in water, oil being then poured on from above. A plate was provided for the receiver, and a water gauge. The whole was very solidly mounted.

This was a version of Huygens' pump: in the same publication Papin described an improved form, shown in figure 8, for which he was entirely responsible. In this the control of the opening was affected by a two-way tap, shown at 'Fig. VI', one channel being an ordinary bore-hole, for

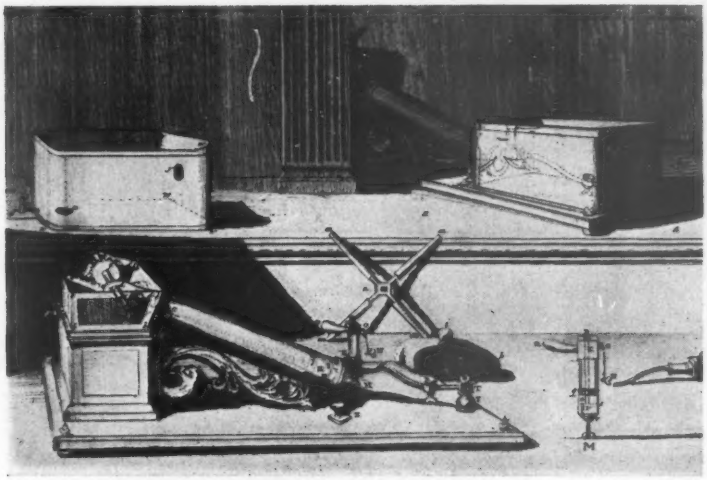


FIGURE 9 – *Senguerd's pump.*

communication with the receiver, and the other a groove along *aa*, for communication with the air. Papin is thus responsible for the invention of the two-way tap, usually attributed to Wolferd Senguerd, who used it in the pump to be next described. The tap in Papin's pump must have been well made, for he found it unnecessary to cover it with water. Another feature of this pump was the stirrup for applying the considerable force necessary to withdraw the piston against the atmospheric pressure.

Wolferd Senguerd's pump, which was much used on the Continent, was first figured in his *Philosophia Naturalis* of 1681, but figured again in more detail in the second edition of this book (1685), where it is very fully described, strangely enough in the preface '*Ad Lectorem*'. Figure 9 is taken from the plate in this preface: further on in the book there is a less detailed representation. Nearly all the German histories of physics, from J. C. Fischer (1802) onwards, say that while the pump was described by Senguerd in 1685 it was not actually made until 1697, and quote as authority Senguerd's *Rationis atque Experimentiae Connubium*, of 1715.[1] Here, however, the author says '*atque ut mihi construeretur, Anno* 1679 *cum Artifice conveni*' ('and I arranged with the artificer to have it constructed for me in the year 1679'). I can only suppose that the first of the historians miscopied 1679 as 1697 and that the others copied him. The mistake is the more remarkable as the engraving gives every sign of having been made from an actual pump.

In Senguerd's pump the barrel is fixed in an oblique position and a two-way tap, shown separately on the right of figure 9, was used to alternate connection with the receiver and with the air. The full description says that, to prevent air leaks, the tap and lower part of the pump may be immersed in water, as shown in the upper part of figure 9. Once more is indicated the difficulty at the time of making airtight joints.

Pumps of the Senguerd pattern were made in large numbers by the famous Dutch instrument maker Jan van Musschenbroek at Leyden, so that examples occur in most collections of historic

[1] The German authorities refer to this as the third edition. It is actually the first and only edition. On the title page, after *Rationis atque Experimentiae Connubium*, with details of the contents, and the author's name, with his titles, stands *Accedit Ejusdem, Disquisitio de Tarantula, Tertio Edita*. The *Tertio Edita* refers to the disquisition on the tarantula only, not to the main book which is here in question.

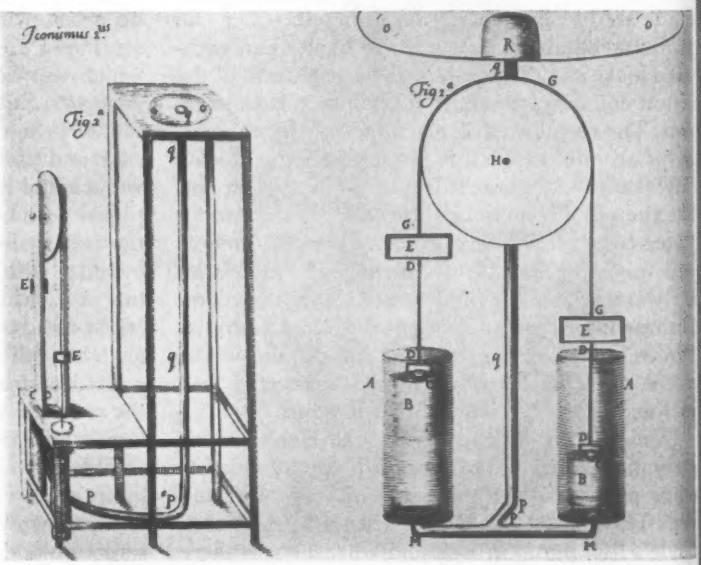


FIGURE 10 – *The two-cylinder pump described by Boyle in* 'A Continuation of New Experiments Physico-Mechanical', 1682.

apparatus. Leutpold likewise favoured the Senguerd type.

In 1675 Papin came to England and worked as assistant to Boyle, who in 1682 described, with due acknowledgment in the Preface, the pump, shown in figure 10, which Papin had brought with him from France. The basic improvement which it embodied was the use of two cylinders, with the pistons coupled together by a cord GGG passing over a wheel, so that the pressure of the atmosphere on one did most of the work required to lift the other—a great saving of labour. The stirrups also made for ease of working.

The culmination of this kind of construction is represented by Francis Hauksbee's pump, described by him in his *Physico-Mechanical Experiments* of 1709 and illustrated in figure 11. A fine example of this pump, corresponding exactly to the illustration, is still preserved by the Royal Society as one of its treasures. Like the last Papin pump, it has two cylinders, but the pistons are worked by rack and pinion. The automatic valves were made of 'limber bladder'. The arrangement of a mercury column manometer, seen immediately under the middle of the bell-jar base, and of the bell-jar itself, is very convenient and the workmanship is excellent.

The bottoms of the cylinders were screwed to a metal base, the connection being made airtight by leather washers, which stood in water retained by the dish *dd*. The connection between the bell-jar and the plate on which it stood was likewise made airtight with wet leather. The pressure could not fall, therefore, below that of saturated water vapour at the prevailing temperature: at 15° C this pressure is about ½ in. of mercury; at 26° C it is 1 in. Hauksbee records on one occasion a height of 29½ in. of mercury, which would be within ½ in. of perfect if the barometric height were normal at the time. On the occasion of a lecture which the writer gave in the character of Francis Hauksbee in 1926 the Royal Society pump was carefully overhauled and put in order, in accordance with the particulars given in Hauksbee's book and not with modern oils, for instance. It than gave regularly a vacuum within about one inch of perfect, corresponding roughly to the vapour pressure of the water.

With such a pump Hauksbee performed the first experiments on the discharge of electricity in vacuo, as described in the *Physico-Mechanical Experiments*, which, as announced on the title-page, contained 'an Account of several Surprizing *Phenomena* touching *Light* and *Electricity*'. The far-reaching consequences of later experiments of this kind need no emphasis.

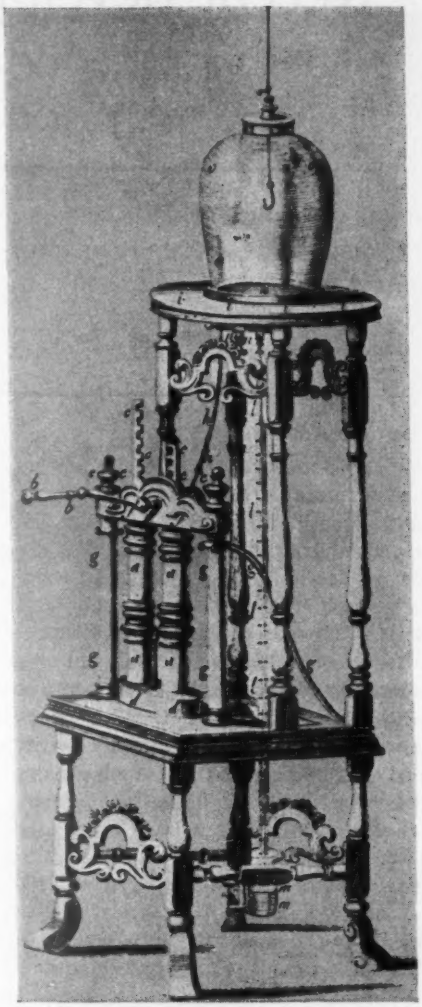


FIGURE 11 – *Francis Hauksbee's pump.*

With Hauksbee's pump a general design was established which remained little changed in essentials until the end of the nineteenth century, when Fleuss introduced the cylinder oil pump, in which all the air was displaced from the dead space by oil, and even here the chief advance was the use of oil having a low vapour pressure. The earliest of the hand-operated pumps which periodically connected the receiver with a freshly created Torricellian vacuum did not appear until 1862, and the first rotary mercury pump was devised by Kaufmann in 1905, soon to be displaced by that of Gaede. So with the worthy Hauksbee, an experimenter of rare gifts, we close the story.

Recent developments in electronic computers

J. M. M. PINKERTON

Electronic computers are now being increasingly used not only in scientific research but in industry and commerce, and much progress has been made in the design and operation of computing machines since this subject was reviewed in ENDEAVOUR eight years ago. This recent progress, and future prospects, are here discussed. An important factor preventing the even more extensive application of computers is a shortage of suitably trained operators.

INTRODUCTION

In the registers of mechanical calculators, numbers are represented by shaft positions and transmitted by gearing the shafts together. In electronic computers numbers are most often represented by electrical pulses or by the magnetic state of a small area of magnetic material, and are transmitted between registers as very short electrical pulses on wires. Thus in respect of the physical representation of such abstract concepts as numbers and instruction codes, there is no essential difference between mechanical and electronic calculators. But because of their much greater speed of operation, and the facility with which electronic circuits can be interconnected and diversified, computers of an order of elaboration altogether different from that feasible with mechanical devices alone have become a practical reality.

In electronic computers numbers may be represented in either the binary or the decimal form: a binary number consists of a series of 0's and 1's representing the presence or absence of successive powers of 2. Most mathematical computers have worked in this system on account of the ease with which it can be physically represented, e.g. by two alternative directions of magnetization in a ring of magnetic oxide [1]. Some computers intended for business calculations have used the decimal system, often by employing the binary representation for each individual decimal digit [2].

A high-speed computer must hold in its store or memory not only the numbers involved in the calculation, but also full instructions governing the course of the calculation to be performed. If this were not so, its extreme speed of operation could not be utilized, since no human operator could give a thousand or more instructions per second. In all modern machines, therefore, instructions (in suitable numerical code) are held in the same store as the numbers. This permits more flexible use of the machine, since the portions of the store assigned respectively to numbers and instructions can be varied according to circumstances. Instructions, being numerical, can themselves be changed inside the machine by simple arithmetical operations. A group of instructions may be arranged to vary according to circumstances a particular instruction which is carried out many times. In this way a dozen instructions may take the place of perhaps a hundred or more.

A hand-operated desk calculator usually has no separate store; numbers are held and arithmetic is performed in the same registers, which are few in number. In the electronic machine it is impracticable to do arithmetic in all registers of the store, numbering from 500 to 2000, so a separate organ known as the arithmetic unit is included. Numbers are taken from store, added, subtracted, multiplied or divided, and afterwards returned to store, all in response to the instructions in the programme. To ensure that instructions are executed in the sequence laid down, central control circuits are provided. These vary greatly but always include a sequence register and an instruction register, a decoding circuit for recognizing the nature of the instruction currently being carried out, and signalling circuits to co-ordinate the activity of all other parts of the machine. Most machines operate one step at a time and can execute from 100 to 10 000 or more steps per second [3].

When new data or instructions are to be presented to the machine, a record must first be made by hand on punched tape, or on cards, or on magnetic tape, to be 'read' automatically by the machine. Reading occurs in response to instructions, as does also printing or punching of results. Results, whether to be read visually or to be held for later use by the computer, must be recorded

VISION

JAN

FIG
The

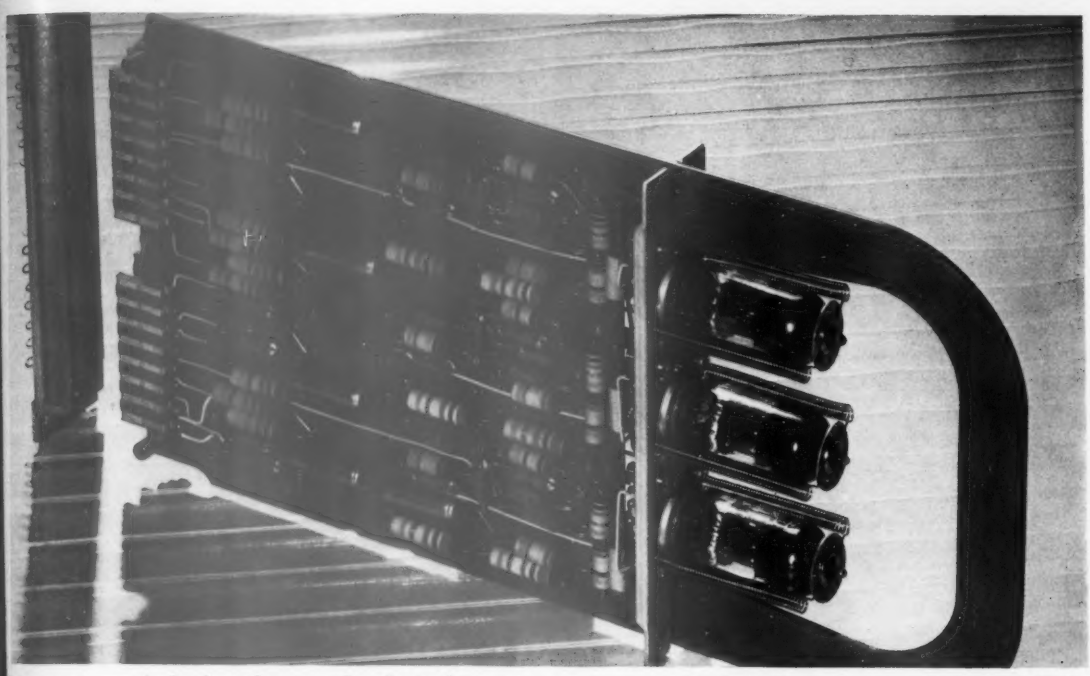
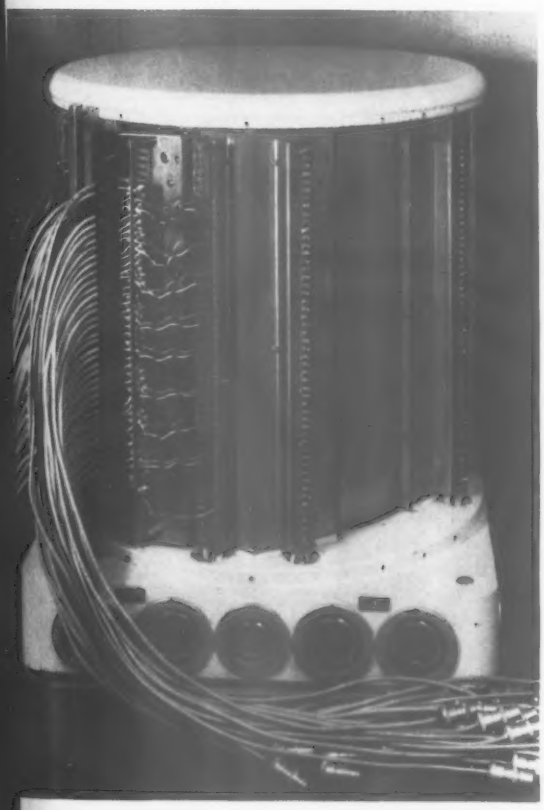


FIGURE 1 – *A circuit package carrying three valves and numerous components, including many germanium crystal diodes. The package plugs into the socket on the left. (Reproduced by courtesy of Ferranti Ltd.)*



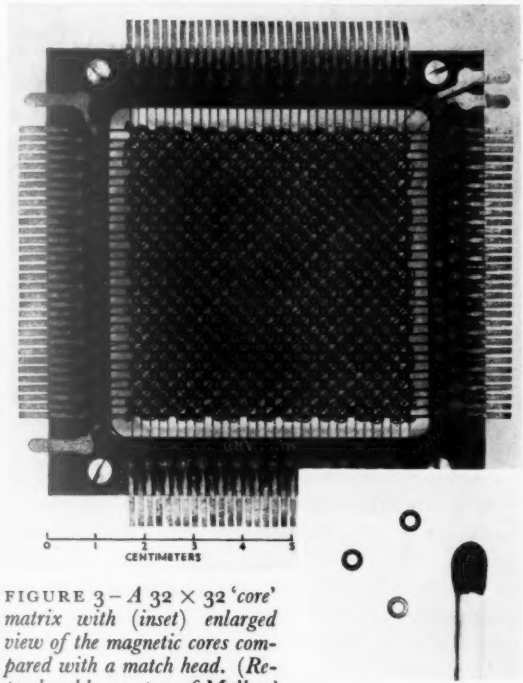


FIGURE 3 – *A 32 × 32 'core' matrix with (inset) enlarged view of the magnetic cores compared with a match head. (Reproduced by courtesy of Mullard Ltd.)*

FIGURE 2 (*left*) – *A magnetic drum. Part of the magnetic surface of the drum is seen on the right and some of the reading and writing 'heads', with leads attached, on the left. (Reproduced by courtesy of Ferranti Ltd.)*

by mechanical means under direct control of the computer. Teleprinters, automatic typewriters, punched-card punches and tabulators, and special high-speed paper tape punches are commonly employed. Magnetic tape recording machines are also used [15]; in this case the numbers on the tape can either be fed back to the computer or printed by an automatic printer dissociated from the computer.

Since both reading and writing instructions involve mechanical operations, they tend to take far longer than calculating instructions. In mathematical machines this is not objectionable, but in business machines far more data and results are involved and special steps are taken to avoid loss of time [7].

HISTORICAL

Some eight years ago D. R. Hartree [8] summarized in ENDEAVOUR contemporary computer developments and was able to mention most of the important projects then in hand. Because of the rapid advances made since then, this is now quite impossible within such a compass. Engineering progress has been especially great, methods of applying machines to mathematical problems have advanced, and machines have been applied commercially to non-mathematical tasks in accountancy and in industrial control [31]. Many machines have been in regular use for six years or more.

In the United Kingdom the most significant scientific developments have occurred in the universities of Manchester [4] and Cambridge [5, 31] and at the National Physical Laboratory at Teddington [6]. At Manchester several computers were built by F. C. Williams and his co-workers at the University, and these have given rise to a series of commercially made examples. At Cambridge emphasis has been on machine use; EDSAC I has been in use since 1949, and a second machine, EDSAC II, is now nearing completion.

In the United States there has been both scientific and commercial development on a prodigious scale. Important research projects on computers have been completed by the Bureau of Standards both in Washington and in Los Angeles [15], at the Massachusetts Institute of Technology [18], and in many other centres. The large accounting machine companies, notably I.B.M. [17] and Remington Rand [2], have been foremost in developing machines for sale or hire. Quite large and complex computers are being constructed by assembly-line methods. A high proportion of the engineering inventions in the field have come from the United States. In Europe the principal developments other than in Britain have been in Sweden and France.

ENGINEERING DEVELOPMENTS

The enormous effort that has gone into this work in the last eight years has been aimed at increasing the speed of operation and the reliability, improving maintenance, and facilitating and cheapening production. The essential features of a machine, however, remain as described by Hartree [8].

The overall speed of a machine is governed principally by the time taken to obtain an item of information from the store. The shorter this time the more expensive does the store become; therefore, to ensure optimum efficiency, machines with 'fast' stores are usually provided with fast arithmetic units, and, if they are to be used for business purposes, with fast input and output organs as well.

The fastest machines operate at 10 000 or more steps per second and now generally use a store based on the magnetic core [1] illustrated in figure 3. Every binary digit stored requires one core to represent its value 0 or 1. The cores are arranged in matrices threaded by wires in the x and y directions; switching circuits are so designed that only if current is passed simultaneously on X and Y wires through a core may its state of magnetization be reversed and a signal be induced in the read-out wire (figure 4). Magnetization of the cores holding 1's is reversed on reading but cores holding 0's are not affected, so that the selected information is cleared on reading and means for regenerating it must be provided.

Medium-speed machines operating at from 700 to 2000 steps per second have used the ultrasonic

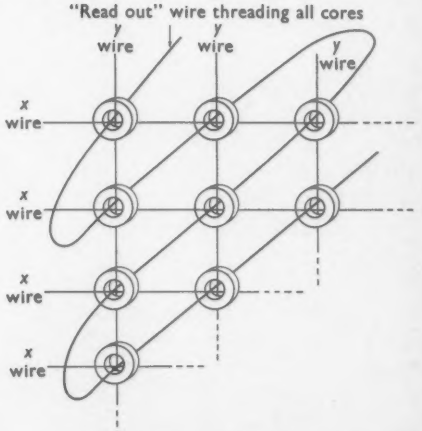


FIGURE 4 – *Construction of a magnetic core matrix.*

1957

es. In
than in

to this
med at
e relia-
litating
ial fea-
scribed

overned
item of
his time
; there-
es with
t arith-
business
as well.
or more
a store
ated in
ires one
ores are
in the s
designed
ously on
state of
induced
zation of
ling but
that the
ing and
ed.
from 700
ltrasonic

---

matrix.

mercury delay line, as for example EDSAC I, or the Williams tube store, as in the Manchester University machine. Another type of delay line [9], using the magnetostrictive effect, is becoming popular, and one machine, NICHOLAS, has used it for its main store [10]. In this an acoustic pulse about two or three microseconds long is transmitted down a nickel wire or tape by passing a current through a small coil near one end. At the other end the reverse magnetostrictive effect induces a small e.m.f. in a similar coil.

In slower machines, particularly in those used for some business purposes, a magnetic drum [19] is now widely used as a main store (figure 2). In the latest designs it is used as a 'backing' store in conjunction with a small fast store employing cores or delay lines. A whole block of orders is transferred from the drum to the fast store, and replaced by another after all orders of the block have been executed. Economy of storage equipment is thus combined with medium speed of operation.

Arithmetic facilities have been extended, not so much by making the machine able to do more than add, subtract, multiply, divide, and shift, as by increasing the flexibility and convenience with which it does these operations. Many machines now perform so-called 'floating-point' arithmetic. In this a number n is represented in two parts, a and b, where $n = a \times 10^b$ (or $n = a \times 2^b$ in the binary system, in which most machines work). After each arithmetical step the part a is automatically adjusted by shifting circuits in the machine to lie between $+1$ and -1. The part b is calculated to correspond, and could range from perhaps $+99$ to -99; numbers held in the machine would then lie between 10^{99} and 10^{-99}. On such a system the velocity of light (299 793 km/sec) would be automatically converted to $0{\cdot}299793 \times 10^6$, i.e. $a = 0{\cdot}299793$ and $b = +6$. This system allows extended calculations without loss of accuracy, even when the position of the decimal point cannot be known in advance.

The input and output systems by which the machine communicates as it were with the outside world have undergone extensive development. Not only have specially rapid readers [20] and printers been developed, but the circuits connecting them to the computer have been much refined. Multiple channels for data and results have been used, particularly in machines designed for business purposes [7]. Punched tape, magnetic tape and punched cards are the most popular media for data and results; many machines have printers directly connected to them in addition.

The mechanical construction of computers has been closely studied; the tendency is to make the electronic circuits in the form of plug-in packages [16]. Originally this was mainly to facilitate maintenance, but it is now seen to make designing less laborious and production easier (figure 1).

In mass-production of any engineering article, methods of standardization to facilitate manufacture are well known. After the parts have been correctly assembled the whole must be given a thorough functional test. A computer could test itself by means of test programmes very thoroughly in a few hours, provided that there were no defects in any of the several hundred units or packages of which it is composed. In practice, however, faults do arise, and since they have to be traced in the complete machine one at a time, the final assembly tests may well take several weeks.

OPERATING TECHNIQUE

It is now recognized that the most important, as well as the most difficult, question is whether a particular computation can be tackled by a computer or not, and if so how it is to be organized. Once this has been decided in complete detail, the stages are usually scheduled on a flow diagram, and programme encoding follows. The first part of this process [13] demands full mathematical insight into the problem; the second part, though laborious and exacting, can be entrusted to trained persons without advanced mathematical knowledge. As written, programmes are seldom free from flaws, and part of the operating time of all machines is devoted to programme trials [21]. Clearly the ratio of preparation time to computing time may be very large, often more than 100 : 1. Thus a problem of the type which has only to be solved once may not be economically tackled by a computer.

In both scientific and business calculations it is vitally important to be able to detect wrong results, though this is not so difficult as it seems. Experience shows that often, though not invariably, a machine produces nonsense or stops when it goes wrong. Mathematical checks are usually put into a programme so that if the data have been correctly recorded and fed into the machine, calculating errors are unlikely to pass undetected. In clerical work the usual accounting procedures can be used to give an absolute check of accuracy of working [11]. Published figures show that most machines achieve about 90–95 per cent reliability. However, the productive efficiency may be appreciably less because time is lost by data and

operating errors as well as by repeating work after breakdowns.

Methods of maintenance are constantly improving; preventive methods of marginal testing, by which gradual deterioration of valves or components is detected before it causes computing errors, are very effective and are now generally used [14]. Finding the faults which occur because of sudden or intermittent failure of some part, commonly a valve, calls for an analytical mind combined with detailed knowledge of the functioning of the machine. Shortage of trained engineers of the necessary quality will probably be the main limitation on the number of machines brought into use in the next few years. Future engineering developments will have to take this into account.

PROGRAMMING

Programming is the art of framing a problem suitably for an automatic calculation and then encoding it for the machine as a series of simple arithmetical steps. The greater art lies in the first stage of this process. This requires the job to be broken into separate stages, each stage corresponding to a separate section in the programme of instructions, e.g. to evaluate $\sin x$ or e^x for a given x. Standard sequences of instructions, known as 'sub-routines', may often be used for such stages, linked together by suitable specially written sequences. Techniques have been worked out, notably by M. V. Wilkes, D. J. Wheeler, and S. Gill [22], on the EDSAC for simplifying the writing of programmes by enabling the stages to be encoded independently, that is self-consistent only within themselves. 'Interpretative sub-routines' then cause the computer, when taking in the separate stages, to modify them as required into a co-ordinated whole. This process can be taken very far indeed, virtually endowing the machine with a new set of arithmetic capabilities, each built up, of course, from a series of simpler steps, but called into play by one 'instruction' which when 'interpreted' causes the machine to go into the required sub-routine. Development in this direction seems limited only by the ingenuity of the programmer.

Programmes could not be written unless the machine could be endowed with a limited power of choice between two paths in a programme. All computers therefore possess special conditional instructions which cause a jump in the orderly progress through the programme if, but only if, some arithmetic criterion is satisfied. This may be the sign of the number in the accumulator register. Thus the machine can be set to repeat a sequence of instructions evaluating the successive terms of a series until no further terms are significant. At this point the machine breaks out of that sequence, sums the significant terms, and proceeds with the next part of the task.

Most machines now have special registers to permit instructions to be modified automatically and to facilitate counting the number of times a sub-routine is carried out. This feature allows, for example, the sum of n numbers to be obtained without having to use valuable storage space to hold n 'add' instructions. It was first used in the Manchester University machine [4]. Besides the purely computing routines in a programme, other routines are required for programme input, data input, and output of results. The latter particularly are often quite complex, as the printer must be instructed to set out the results on the paper: for example, an output routine has been devised to make the machine plot directly a Patterson projection in X-ray crystallography [23].

APPLICATIONS OF COMPUTERS

Computers have been used to solve a great range of scientific and technical problems [24, 25], to a limited extent to test mathematical theorems in the theory of numbers [12], and to do some of the routine calculations of commerce. The list of applications is so long that only a few can be mentioned here.

The EDSAC has been successfully used by J. C. Kendrew and J. M. Bennett [23] for computing both two- and three-dimensional Fourier syntheses from X-ray crystallographic data, and by I. W. Cochran and A. S. Douglas [26] to obtain the sign of the Fourier coefficients. Numerical solutions have been found to partial differential equations [25], and mathematical tables of functions prepared [13]. Optical problems in tracing rays through compound lenses have been solved [27]. Experiments have been made to determine whether a computer can be used in weather forecasting. Trial forecasting charts have been evaluated on a computer by F. H. Bushby and M. K. Hinds [28], using the Sawyer-Bushby model of the atmosphere. Results for 12- and 24-hour periods were encouraging, although difficulties arose in dealing with conditions at the boundaries of the area, which covered the United Kingdom and the North Atlantic as far as the seaboard of the United States.

Many problems have been solved correctly that

could not have been tackled by hand methods of computation not only because of the labour involved, but because of the chance of a mistake vitiating the entire calculation. As an example may be cited the computing of the co-ordinates of the five outer planets at 40-day intervals for the period 1653 to 2060. This was done jointly by the U.S. Naval Observatory in Washington, the Yale University Observatory and the I.B.M. Corporation using the Selective Sequence Calculator [29]. The mutual attractions of the five planets and the Sun were expressed by a set of simultaneous non-linear differential equations of the 30th order, which were solved to an accuracy of 14 decimals. The resulting coordinates correctly represent the observations over a period of 150 years within the probable error and are more accurate than those obtained from Hill's Tables.

A computer has recently been used to control a milling machine by absorbing data from an engineering drawing and punching out instructions into paper tape. The tape is 'read' and controls the movements of the workpiece in three dimensions by very accurate servo mechanisms. The same tape can be used many times, and one computer can easily provide control tapes for many machine tools [30].

Commercial clerical work, provided that it is of a repetitive and routine character, can be transferred to a computer so that all the steps can be specified exactly in advance. It is, however, unnecessary that every stage should be performed in the same way each time the routine is carried out. In payroll calculation, for example, one man may have worked normally, another have been sick, a third on holiday, and so on; all these variations are dealt with by appropriate sections of the programme, and instructions that do not apply are short-circuited. It is the ability to deal with the widely varying circumstances of everyday business that makes a computer so valuable in an office. Whether it is economical to do office work by machine depends on whether there is a sufficient volume of routine work to justify the initial cost of the machine and the trouble and expense of re-planning the work for the computer. A large computer, LEO, a development of the Cambridge EDSAC, with multi-channel input and output facilities, has been in regular daily use for over two years in Britain in the offices of a large catering firm [7, 11].

The rate of progress is being limited by the scarcity of engineers, mathematicians, and accountants with experience of using computers. In an effort to overcome the shortage, the tendency will be towards standardization of the computer as a whole and more particularly of its parts, the programming techniques and operating methods.

REFERENCES

[1] RAJCHMAN, J. A. *RCA Review*, 13, 183, 1952.
[2] WEINER, J. R. *Trans. I.R.E. Prof. Group on Electronic Computers*, 1, 33, 1952.
[3] BOWDEN, B. V. (Editor). 'Faster than Thought'. Ch. 3. Sir Isaac Pitman and Sons, London. 1953.
[4] *Ibid.* Ch. 6.
[5] *Ibid.* Ch. 7.
[6] *Ibid.* Ch. 8.
[7] PINKERTON, J. M. M. and KAYE, E. J. *Electronic Engng*, 26, 284, 1954.
[8] HARTREE, D. R. *Endeavour*, 8, 65, 1949.
[9] BRADBURD, E. M. *Elec. Commun.*, 28, 46, 1951.
[10] HILL, N. D. Automatic Digital Computation (Proceedings of National Physical Laboratory Symposium, 1953), p. 46. Her Majesty's Stationery Office, London. 1954.
[11] THOMPSON, T. R. *Ibid.*, p. 85.
[12] MILLER, J. C. P. *Ibid.*, p. 160.
[13] HARTREE, D. R. 'Numerical Analysis'. Clarendon Press, Oxford. 1952.
[14] TAYLOR, N. H. *Proc. Inst. Radio Engrs*, 38, 1418, 1950.
[15] Computer Development at the National Bureau of Standards, N.B.S. Circular No. 551, Washington. 1955.
[16] LEINER, A. L., ALEXANDER, S. N., and WITT, R. P. *Ibid.*, p. 55.
[17] BUCHOLZ, W. *Proc. Inst. Radio Engrs*, 41, 1262, 1953.
[18] EVERETT, R. R. *Elec. Engng*, 71, 681, 1952.
[19] WILLIAMS, F. C., KILBURN, T., and THOMAS, G. E. *Proc. Instn elect. Engrs, Pt* II, 99, 94, 1952.
[20] WELBY, B. G. *Electronics*, 26, 115, 1953.
[21] GILL, S. *Proc. roy. Soc., A*, 206, 538, 1951.
[22] WILKES, M. V., WHEELER, D. J., and GILL, S. 'The Preparation of Programmes for an Electronic Digital Computer'. Addison-Wesley Press, Cambridge, Mass. 1951.
[23] BENNETT, J. M. and KENDREW, J. C. *Acta Cryst.*, 5, 109, 1952.
[24] BROOKER, R. A. *Brit. J. appl. Phys.*, 4, 321, 1953.
[25] SHELDON, J. and THOMAS, L. H. *J. appl. Phys.*, 24, 235, 1953.
[26] COCHRAN, I. W. and DOUGLAS, A. S. *Proc. roy. Soc., A*, 227, 486, 1955.
[27] BLACK, G. *Proc. phys. Soc., B*, 67, 569, 1954.
[28] BUSHBY, F. H. and HINDS, M. K. *Quart. J. roy. Meteorol. Soc.*, 80, 165, 1954.
[29] *Astr. Pap., Wash.*, 12, 1951.
CLEMENCE, G. M., and BROUWER, D. *Astr. J.*, 60, 118, 1955.
[30] *Electronic Engng*, 28, 204, 1956.
[31] WILKES, M. V. 'Automatic Digital Computers'. Methuen, London. 1956.

Polar and tropical aurorae

JAMES PATON

It is not generally known that aurora, typically a phenomenon of high latitudes, occasionally occurs also in low latitudes, even near the equator. Further knowledge of these low-latitude displays is urgently needed to amplify our understanding of auroral processes, and observation of them is an important part of the programme of the forthcoming International Geophysical Year. ENDEAVOUR welcomes the opportunity of lending its support to an appeal, contained in this general review of auroral phenomena, for reliable reports of their occurrence in low latitudes during the Geophysical Year commencing on 1st July 195

The upper atmosphere over the whole earth continuously emits a feeble light, but even on a moonless night this airglow is usually too weak to be visible to the eye. There is, however, an almost continuous emission of much stronger light which is easily visible during the dark hours in two zones girdling the earth at about 23° from the north and south magnetic poles respectively. This is aurora: aurora borealis in the northern hemisphere and aurora australis in the southern hemisphere. During the period of sunspot maximum, aurora may extend far from its normal zones for periods of many hours, and may become visible over a large area of the globe stretching from the poles sometimes almost to the equator. When the luminosity increases beyond the threshold of colour perception, observers are treated to a weirdly pulsating display of variegated colour in the sky, of a magnificence that beggars description. So fantastic may be the appearance of a great aurora that it has been known to excite apprehension, even panic, among those unfamiliar with it.

The light of aurora is produced quite differently from that of the airglow. The latter derives its energy from the store accumulated during the day, when solar ultra-violet light ionizes and dissociates the atmospheric gases at great heights. The resultant chemical reactions among the ionized and dissociated products release the stored energy in the form of radiation (the night airglow), which is therefore emitted over the whole globe. Aurora, on the other hand, is caused by the entry into the high atmosphere of a stream of charged particles, ions and electrons, originating in the sun. Electromagnetic deflection by the earth's magnetic field causes the stream of particles to precipitate over limited regions of the earth, the precise zone of precipitation depending on the speed, constitution, and direction of incidence of the stream. The auroral light is emitted mainly by the bombarded atmospheric gases, and sometimes also by protons in the incident stream which have captured an electron.

Since aurora is visible on every clear night in the northern and southern auroral zones, it appears that a stream of corpuscles of solar origin continuously approaches the earth with a speed and density such as to limit precipitation to these zones. Besides causing aurora, the solar corpuscular stream increases the ionization during its passage through the upper atmosphere and produces changes in the ionosphere. These in turn produce changes in the upper atmospheric current systems that reveal their presence by perturbations in the earth's magnetic field. It is not surprising, therefore, that the intensity of geomagnetic disturbance is normally greatest near geomagnetic latitude 67°, i.e. in the auroral zone.

A great aurora that is seen widely over the earth generally follows the occurrence of an intense flare or eruption in the central portion of the sun's disk. This observation provided, in fact, the first convincing evidence for the solar origin of aurora. The sequence of terrestrial events that accompany and follow the flare is as follows. Almost simultaneously with the flare occur a short-wave radio fade-out and magnetic crochet, i.e. a small but sudden disturbance in the earth's field. These effects, being confined to the sunlit side of the earth, are undoubtedly caused by the intense ionization in the upper atmosphere produced by a burst of ultra-violet light from the flare; this burst takes a mere eight minutes to reach the earth. It is not until about 24 hours later, however, that there occur a great and widespread aurora and a magnetic disturbance so severe as to earn the name 'magnetic storm'. The delay in the occurrence of these later phenomena is more readily explained by the assumption that they are caused when a stream of material particles

X

JA

F

FIGURE 1 – *Rayed band developing into curtain.*

FIGURE 2 – ***Rays seen through glow on horizon.***

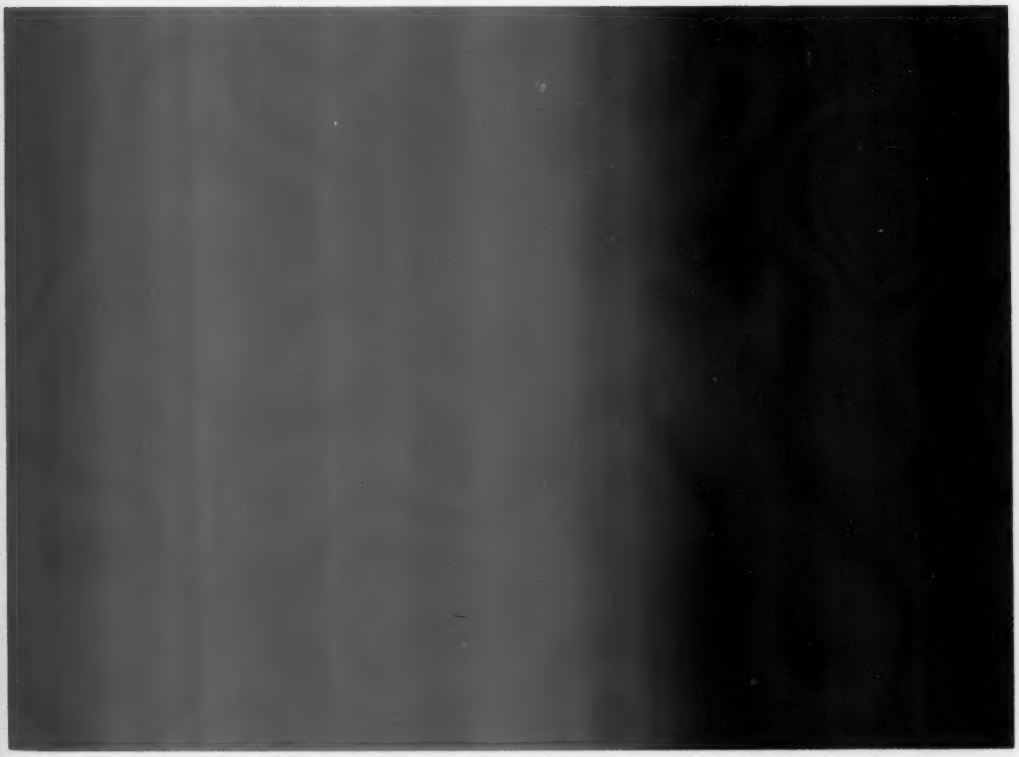


FIGURE 3 – *A corona.*

FIGURE 4 – *The top of a quiet, diffuse arc.*

FIGURE 5 – *The diffuse arc shown in figure 4 bursts into rays.*

V
16
1
JA
N
5
7
XU

ejected from the sun at the time of the flare, enters the upper atmosphere after making the journey from sun to earth in 24 hours; on this reasoning the speed of the particles must be of the order of 1500 km per second. Since flares are closely associated with sunspots, auroral occurrences in regions farther from the auroral zones than, say, the north of England (geomagnetic latitude 57°) follow the eleven-year sunspot cycle.

During the years of sunspot minimum, however, aurora continues to be seen quite frequently even as far from the auroral zones as the north of England. These aurorae recur at 27-day intervals, and are thought to be caused by a particle stream which, for a long period, continues to issue, rather like a jet of water from a hose, from a restricted area of the sun: this has been called an M-region by J. Bartels. The period of rotation of the sun, as observed from the earth, being about 27 days, such a stream would sweep across the earth with this periodicity, causing these recurrent aurorae to become visible in regions within about 10° of the auroral zones.

The behaviour in the earth's magnetic field of a solar stream consisting of ions and electrons, but with no overall charge (see page 46), approaching and sweeping past the earth, has been examined theoretically by S. Chapman and V. C. A. Ferraro [1] and by H. Alfvén [2]. The problem is of the utmost difficulty and little progress has been made towards a satisfactory theory of aurora, though Chapman and Ferraro may have provided an acceptable explanation of the initial stages of a magnetic storm. While the emission of auroral light is generally thought to result mainly from the excitation and ionization of atmospheric atoms and molecules directly by the primary particles in the solar stream, or by secondary electrons ejected during their passage through the atmosphere, Alfvén regards aurora as a gaseous discharge which may carry current between space charges, associated with the stream at a great distance from the earth, and the ionosphere.

Aurora is on the average visible on perhaps ten nights of the year in the south of England, northern France and Germany, and the northern parts of the United States. Usually it appears in these places merely as a glow along the northern horizon, closely resembling dawn (figure 2). Indeed, it acquired its name aurora borealis, the northern dawn, from its usual appearance to observers in these populous regions. It belies this name during a great display, when the glow ascends in the sky to form a quiet and regular arc (figure 4); later the arc suddenly brightens and disintegrates into a series of irregular rayed bands (figure 5), whose folds cause them to appear like huge curtains waving in the sky (figure 1). When streamers or rays extend overhead from the draperies into the southern sky, they appear by perspective to converge to the point in the sky to which the south pole of a magnetic dip needle is directed. The streamers are therefore parallel, and coincide with the lines of force of the earth's field. This most striking of auroral forms is called a corona (figure 3). As the display reaches its climax and begins to recede northwards, there is usually much flaming; waves of light surge upwards from the horizon to the zenith.

Investigation of the auroral spectrum is important not only for the information it may yield concerning the origin of aurora but because it provides a means of determining the composition and properties of the atmosphere at the levels where auroral light is emitted. The experimental difficulties are formidable, for the intrinsic luminosity is low and the brightest auroral forms are usually in rapid movement. Further, the long time-interval between successive collisions of atoms and molecules in the upper atmosphere leads to emissions associated with transitions that violate the selection rules, i.e. to so-called forbidden emissions, which cannot easily be reproduced in the laboratory. The identification of the origin of spectral lines is therefore often difficult, and the lines themselves may sometimes be obscured by overlapping band-systems. Lines of neutral and ionized atomic oxygen and nitrogen and band systems of neutral and ionized molecular oxygen and nitrogen have been identified. The processes that may be responsible for the various emissions are numerous and have recently been examined by D. R. Bates [3].

The recent use of spectrographs of great resolving and light-gathering power, which provide measurable spectra with short exposure times, has made possible the examination of the spectral characteristics of short-lived auroral features. In this way emissions of lines by elements present in the incident solar stream that causes aurora have been identified. The Balmer lines of hydrogen were first identified by L. Vegard and confirmed by C. W. Gartlein. The measurement by A. B. Meinel [4] of the Doppler displacement of the Hα line in the spectrum of an arc near the zenith showed that protons in the incident solar stream possessed velocities of the order of 3300 km per second. Since their light emission can occur only when the proton has been slowed down sufficiently

to capture an electron, the speed with which the protons enter the upper atmosphere must be considerably greater than that determined from the Doppler shift. The Hα emission was observed to cease when the quiet arc disintegrated into rays, so apparently protons play no part in the formation of rays. There is some spectral evidence that sodium also is present in the solar stream.

We owe much of our knowledge of general auroral characteristics to the great work of Carl Störmer and his colleagues in Norway. Störmer was attracted to this study in the early years of the century on seeing a spectacular experiment performed by his colleague Kristian Birkeland. In an attempt to reproduce aurora in the laboratory Birkeland exposed a magnetized sphere, simulating the earth, to a stream of cathode rays in a large discharge vessel. The precipitations of the rays on the sphere were made visible by the fluorescence of a coating material and, by suitable adjustments, could be made to take the form of well defined spirals round each pole. This apparently close experimental reproduction of aurora inspired Störmer [5] to embark on the difficult and laborious task of computing numerically the trajectories of an electron moving in the field of a dipole, and he has thus provided explanations of some of the forms assumed by aurora. The objection to the hypothesis of a stream of particles all carrying charge of the same sign is that mutual electrostatic repulsion would disperse it long before it reached the earth. It is for this reason that the more recent theories are based on a solar stream consisting of ions and electrons. An extension of Störmer's classic work has, however, an important application in cosmic ray theory.

When Störmer began his theoretical work, accurate information concerning the height and disposition in space of the various auroral forms was lacking. He therefore devised an ingenious photographic method [5] of making these measurements, which were necessary for the verification of the theory. Using specially designed cameras, simultaneous exposures are made on the same feature of an aurora at two or more stations separated by distances of from thirty to a few hundreds of kilometres. By measuring the parallactic displacement, with reference to the star background, of corresponding auroral points on a pair of pictures, height and position are determined. By this method Störmer found that the brightest auroral features are usually situated at heights near to 100 km, though they may occasionally come as low as 70 km. He found that near dawn or sunset, rays may extend to enormous heights—to as high as 1000 km.

The photographic study of aurora is limited to the periods during the dark hours when the sky is clear. But there can be little doubt that aurora occurs by day as well as by night, for the magnetic storm which accompanies aurora by night continues during the day. Radio-echo methods now being developed may afford a means of making a continuous study of the phenomenon uninterrupted by cloud, moonlight, twilight, or daylight. During the Polar Year of 1932–33, E. V. Appleton and his colleagues [6] showed that aurora is accompanied by an increase in ionization below the E-layer of such intensity that at these times investigation of ionospheric conditions by conventional probing methods using frequencies in the range 1–20 Mc/s is impossible, so great is the attenuation produced. It was later found, however, that echoes could be obtained during auroral activity by using higher frequencies. In 1947 A. C. B. Lovell and his colleagues [7] at the Jodrell Bank Experimental Station, using a frequency of 46 Mc/s, recorded reflections that appeared to come from a luminescent cloud at the end of a ray. Similar observations have since been made in Scandinavia and North America. The interpretation of the origin of the echoes is still uncertain. Some experimenters [8], finding no correspondence between the range of the echoes and the position of the auroral forms, propose that they are not true echoes from aurora but simply back-scatter from the earth's surface, the sounding pulse of radiation travelling outwards by reflection at the abnormal E-layer and backwards by a similar path. But most observations suggest that the echoes are produced either by scattering from columns of ionization associated with auroral rays or by total reflection at dense isotropic clouds of ionization [9]. Thus investigation by radio-echo methods has so far yielded only limited information; indeed, just at the time of night when aurora is most frequently observed visually (about 21 hrs G.M.T. in Britain) the rate of occurrence of radio echoes is at a minimum.

AURORA IN THE GEOPHYSICAL YEAR

On 1st July 1957 geophysicists all over the globe will begin observations on an internationally agreed plan for a study of the earth and its atmosphere [10]. Included in this are elaborate plans for a world-wide study of aurora, using all the techniques available. This work will naturally be concentrated in regions in and near the auroral

zones, but since the International Geophysical Year (I.G.Y.) has purposely been chosen to coincide with the period of maximum sunspot activity, during this period aurora is certain to be seen at times in low latitudes, perhaps even close to the equator. Though there are substantiated accounts of observations of aurora in tropical regions—it was seen, for example, in Singapore (latitude 1° N) on 25th September 1909—Professor S. Chapman, chairman of the special committee for the I.G.Y. and co-ordinator of the aurora observation programme, after searching all available records has found no adequate observations of the characteristics of a tropical aurora. He has stressed the importance of obtaining such observations during the I.G.Y., pointing out that the intensive studies undertaken in and near the auroral zones will be incomplete if details of aurorae that penetrate to low latitudes are lacking [11]. It is therefore important to arouse the interest of all observers in tropical and subtropical regions—and not merely those formally associated with the I.G.Y. programme—in the phenomenon and to make them aware of the fact that they are in a position to provide information of great value simply by using their eyes and recording accurately the form of any unusual luminosity that they may see in the night sky.

During the I.G.Y. a continuous watch will be kept on the surface of the sun at solar observatories, and warning will be issued from a World Prediction Centre when solar activity indicates that a widespread aurora is more likely than usual. The warnings will be immediately distributed among all those involved in auroral and related investigations, and also will be announced in news bulletins of radio services throughout the world. It is hoped that observers in low latitudes will then look out for aurora in the night sky and make an accurately timed record of its progress when it becomes visible. Crews of aircraft flying in tropical regions are particularly favoured from the point of view of sky observation, since cloud is less likely to interfere and they may see more distant aurorae than the land-based observer. While in the majority of cases the watch for aurora may go unrewarded, the probability of witnessing a rare spectacle is sufficiently high to justify regular observation. Since the chance of seeing aurora is greater the nearer the observer is to the magnetic pole, successful observation of a tropical aurora is more likely, for example, in Central America than in southern India.

While it is most important that watch for tropical aurorae be kept during the I.G.Y., when there is world-wide observation of all geophysical phenomena, it is very desirable that auroral observation be continued for a year or two afterwards, because past observations have shown that solar-terrestrial effects tend to be greatest in the years following the sunspot maximum.

Assistance in searching official records, newspapers, ships' logs, diaries, and letters for accounts of past tropical aurorae would also be welcome.

The dates of the twelve greatest magnetic storms recorded at Greenwich during the period 1874–1954 are: 1882, 17th and 20th November; 1903, 31st October; 1909, 25th September; 1921, 13th May; 1938, 25th January and 16th April; 1940, 24th March; 1941, 1st March and 18th September; 1946, 28th March and 21st September. The study of documents relating to the time of their occurrence is particularly likely to be fruitful. Further particulars of the tropical aurorae of 1859 (28th August to 2nd September) and 1872 (4th February) would also be valuable.

Detailed observations of low-latitude aurorae in combination with other information amassed during the I.G.Y. may make it possible for the first time to piece together world synoptic pictures showing successive stages in the development and decay of a great aurora.

Reports of tropical aurorae and any inquiries relating to auroral observations should be sent to the writer of this article (Mr J. Paton, Department of Natural Philosophy, The University, Edinburgh, Great Britain), who is correspondent for the Aurora and Airglow Section of the British National Committee for the I.G.Y.

REFERENCES

[1] CHAPMAN, S. and BARTELS, J. 'Geomagnetism'. Clarendon Press, Oxford. 1940.
[2] ALFVÉN, H. 'Cosmical Electrodynamics'. *Ibid.*, 1950.
[3] BATES, D. R. *Ann. Géophys.*, **11**, 3, 1955.
[4] MEINEL, A. B. *Astrophys. J.*, **113**, 50, 1951.
[5] STÖRMER, C. 'The Polar Aurora'. Clarendon Press, Oxford. 1955.
[6] APPLETON, E. V., NAISMITH, R., and BUILDER, G. *Phil. Trans., A*, **236**, 191, 1937.
[7] LOVELL, A. C. B., CLEGG, J. A., and ELLYET, C. D. *Nature, Lond.*, **160**, 372, 1947.
[8] HARANG, L. and LANDMARK, B. *J. atmos. terr. Phys.*, **4**, 322, 1954.
[9] BOOKER, H. G. *Ibid.*, **8**, 204, 1956.
[10] *Endeavour*, **14**, 59, 1955.
[11] CHAPMAN, S. The aurora in middle and low latitudes. Chapter of I.G.Y. Auroral Manual. (In press.)

The structure of insulin

F. SANGER and L. F. SMITH

The biological importance of proteins needs no emphasis, for they play a remarkable variety of roles. Some, such as collagen or keratin, are structural; others, such as actomyosin and haemoglobin, perform specific chemical functions. Others function as enzymes, selectively catalysing metabolic processes. The hormone insulin, which is concerned with the regulation of glucose metabolism and is used in the control of diabetes, is a protein of exceptional importance, and the recent elucidation of its structure is a chemical feat of the first order.

Most of the energy for the body is derived from the breakdown of glucose, and it is essential that the glucose concentration in the blood should remain relatively constant. If it becomes too low, convulsions and shock result; if it is too high, coma may occur. It is thus necessary for the body to have a means of controlling the level of glucose in the blood, and insulin is one of the main factors involved in this. It is produced by the islets of Langerhans, groups of cells situated in the pancreas. When the blood glucose level is high, these cells are stimulated, insulin is secreted into the blood and transported throughout the body, where—by some unknown process—it catalyses the removal of glucose from the blood. In diabetes, the functioning of the islets of Langerhans is impaired and they cease to secrete sufficient insulin to keep the blood glucose low enough, and this leads to the characteristic symptoms of the disease. These can be alleviated by injecting insulin, which is now prepared on a large scale from the pancreases of cattle or other animals.

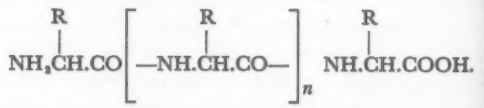
Whatever the physiological function of a particular compound, it is clear that it will depend on the substance's exact chemical structure. It is therefore not surprising that much effort has been devoted to the study of proteins, since these play such a remarkable diversity of biological roles. Progress in this field has, however, been slow because of the large size and extreme complexity of protein molecules. Only recently has it been possible to write the complete chemical formula for even one protein. This protein is insulin, and the work on its structure is the subject of the present article.

Much work has been devoted to the determination of the molecular weights of proteins. In general they have been found to be large molecules with molecular weights lying between about 5000 and several million. Insulin is one of the smallest, having a molecular weight of 5733 [1, 2]. In aqueous solution, however, it undergoes aggregation, so that the apparent particle weight is considerably greater.

The fundamental components from which proteins are built up are the amino acids, most of which have the general formula

$$R.CH(NH_2).COOH.$$

Twenty-one of these acids, differing in the nature of the R group, occur commonly in most proteins: they are listed in Table I. Insulin contains all of them except methionine, tryptophan, and cysteine. The amino acid residues are joined together in proteins by the formation of amide or peptide bonds between the α-carboxyl group of one residue and the α-amino group of another. In this way they form long polypeptide chains of the general structure:



When a protein is hydrolysed with strong acid, the peptide bonds are broken and a mixture of the component amino acids is obtained: by suitable analytical procedures the number of residues of each can be determined. In this way it was possible to write an empirical formula for insulin in terms of its amino acid content (table I); the next problem was to find how the amino acid residues were arranged together in the molecule.

From the formula for a polypeptide chain given earlier we can distinguish three types of residues. Most of the amino acids are present in the form —NH.CHR.CO—; that is, with their amino and carboxyl groups blocked. On the left of the formula is a residue with a free α-amino group ($NH_2CHR.CO$—). This is known as the N-terminal residue, and by making use of suitable chemical reactions it is possible to identify and

TABLE I

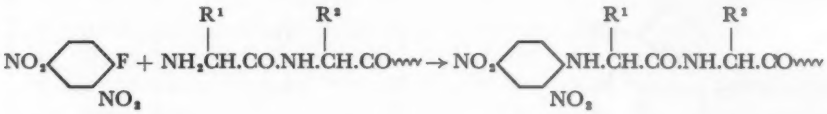
Common naturally occurring amino acids

Amino acid	*Structure of R group*	*Abbreviation used for residue —NH—CH(R)—CO—*	*Number of residues in insulin*
Aliphatic			
Glycine	—H	Gly	4
Alanine	—CH_3	Ala	3
Valine	—CH(CH_3)(CH_3)	Val	5
Leucine	—CH_2—CH(CH_3)(CH_3)	Leu	6
Isoleucine	—CH(CH_3)—CH_2—CH_3	Ileu	1
Serine	—CH_2—OH	Ser	3
Threonine	—CH(OH)—CH_3	Thr	1
Aromatic			
Phenylalanine	—CH_2—C_6H_5	Phe	3
Tyrosine	—CH_2—C_6H_4—OH	Tyr	4
Tryptophan	—CH_2—C_8H_6N	Try	0
Acidic			
Aspartic acid	—CH_2—COOH	Asp	0
Glutamic acid	—CH_2—CH_2—COOH	Glu	4
Acid amides			
Asparagine	—CH_2—$CONH_2$	$AspNH_2$	3
Glutamine	—CH_2—CH_2—$CONH_2$	$GluNH_2$	3
Basic			
Lysine	—CH_2—CH_2—CH_2—CH_2—NH_2	Lys	1
Arginine	—CH_2—CH_2—CH_2—NH—C(=NH)—NH_2	Arg	1
Histidine	—CH_2—$C_3H_3N_2$	His	2
S-containing			
Cysteine	—CH_2—SH	CySH	0
Cystine	—CH_2—S—S—CH_2—	CyS—CyS	3
Methionine	—CH_2—CH_2—S—CH_3	Met	0
Cyclized			
Proline	H_2C—CH_2* H_2C CH—COOH N H	Pro	1

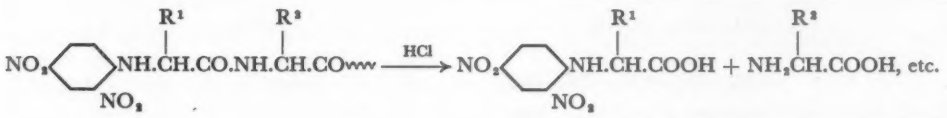
* Complete structure of the amino acid.

estimate such residues. At the other end of the chain is the C-terminal residue, which has a free α-carboxyl group. The study of terminal residues has assumed considerable importance in protein chemistry, since not only is it possible to locate the position of certain residues in the chain in this way, but it also gives some information about the general overall structure of the protein. It can be used for the characterization of a protein and is a useful test of purity [3–5]. Since each open polypeptide chain has one N-terminal and one C-terminal residue, an estimation of these can be used to determine the number of chains present, provided there are no cyclic or branched chains.

As an initial attack on the insulin molecule a general method was developed for the identification and estimation of N-terminal residues [6]. 1-fluoro-2:4-dinitrobenzene (FDNB) reacts with amino groups of peptides and proteins to give dinitrophenyl (DNP) compounds:

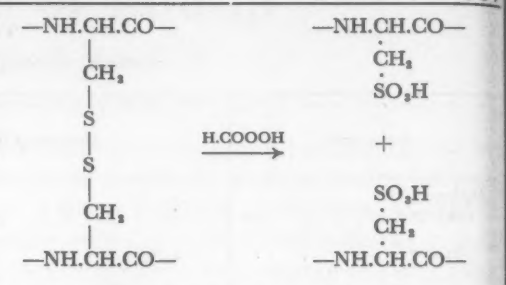


On acid hydrolysis this new bond is in general more stable than peptide bonds, so that one obtains amino acids and the DNP derivative of the N-terminal residue:



The yellow DNP-amino acids can be isolated and identified by chromatography on silica gel columns or on filter paper. By this method both glycine and phenylalanine were found to occupy N-terminal positions in insulin, suggesting that there were at least two polypeptide chains in the molecule, one having N-terminal glycine and the other an N-terminal phenylalanine residue.

Insulin contains three residues of cystine, and as can be seen from its structure (figure 1), this amino acid is capable of linking two polypeptide chains together through a disulphide bond. To break these disulphide cross-links insulin was oxidized with performic acid, which converts one residue of cystine to two residues of cysteic acid (abbreviated $CySO_3H$)



After this treatment it was possible to isolate two fractions: one acidic, having only N-terminal glycine (fraction A), the other basic, having only N-terminal phenylalanine (fraction B) [7]. Further evidence showed that each fraction was homogeneous and that the A chain had 21 amino acid residues, of which four were cysteic acid, and the B chain 30 residues, of which two were cysteic acid. In this way the insulin molecule had been split into its two constituent polypeptide chains; this simplified the next problem, which was to determine the complete sequence of amino acids in the two chains.

The basis of the method used can be illustrated in the following manner. If we have a dipeptide the amino acid composition may be determined after complete hydrolysis of a sample. Suppose it gives two amino acids, A and B. Another sample is treated with FDNB and the N-terminal amino acid determined. If this is A, then the structure of the dipeptide must be A.B (by convention the amino acid having the free amino group is written on the left). This reasoning can be extended to give the structure of larger peptides by first partially hydrolysing them to give a series of dipeptides the structures of which can be proved; the structure of the large peptide can be deduced from these. Thus a peptide A.B.C.D on partial hydrolysis might produce dipeptides A.B, B.C, and C.D, from which a unique sequence for the tetrapeptide could be deduced. If a particular residue occurs more than once in a peptide the complete structure cannot be worked out from

dipeptides and it is necessary to obtain some larger peptides.

This was basically the method applied to the elucidation of the amino acid sequence of the A and B chains of insulin. The difficulty with large polypeptides of this nature was the technical one of isolating the peptides from a partial hydrolysate, for if the procedure outlined above is to be valid the peptides must be pure. Thus from a linear polypeptide of 30 residues such as fraction B, one could get 29 dipeptides, 28 tripeptides, 27 tetrapeptides, etc. In actual practice it is possible to reduce this number in two ways. If the polypeptide is being hydrolysed with acid, the hydrolysis is continued for a sufficient time to ensure that most of the larger peptides have been broken down and that the mixture contains only small peptides and free amino acids. Another method is to hydrolyse with proteolytic enzymes. In this way only peptide bonds adjacent to certain amino acids are broken. For instance, trypsin, a pancreatic enzyme, will hydrolyse only peptide bonds formed by the carboxyl groups of lysine or arginine. Thus a peptide Gly.Glu.Arg.Gly.Phe, which could give four dipeptides, three tripeptides, and two tetrapeptides on acid hydrolysis, would give only two peptides—Gly.Glu.Arg and Gly.Phe —after treatment with trypsin. Even with these two methods of partial hydrolysis the fractionation of the peptides produced was still a major problem, and it was only after the introduction of paper chromatography [8, 3, 9] that it was possible to attempt to fractionate such complex mixtures. This proved to be the most useful method throughout this work, especially for the small peptides produced by acid hydrolysis. With large peptides better separations were usually obtained by electrophoresis on paper [10, 11, 13]. Ion exchange and adsorption chromatography have also been used for preliminary fractionations of the mixtures.

As an example, we can show how one part of the sequence of the B chain was deduced. Aspartic acid occurs only once in the chain, and therefore any peptide containing aspartic acid must be part of a single sequence. Two dipeptides, Val.Asp and Asp.Glu, were found in a partial acid hydrolysate giving the sequence Val.Asp.Glu. This was confirmed by the identification of a tripeptide Val.(Asp,Glu). (The inclusion of the residues in brackets in the formulae for peptides indicates that their relative order is unknown.) Another tripeptide Phe.(Asp,Val) extended the sequence to Phe.Val.Asp.Glu and a pentapeptide Phe. (Asp, Glu,His,Val) suggested that the residue following glutamic acid was histidine.

From the small peptides produced by partial acid hydrolysis many sequences were deduced, but it was not possible to determine the complete sequence of the B chain by this method; for instance, no peptide containing serine was found in which serine did not occupy the N-terminal position. This suggested that the peptide bond formed by the amino group of serine was very labile and under the conditions used was always broken, thus making it impossible to determine which amino acid preceded serine. In order to complete the sequence it was necessary to study the larger peptides produced by enzymic hydrolysis, and in this way the structures of both the A and the B chains were determined [12, 13] and are shown in figure 1. The —NH_2 groups indicate the presence of the amide residues asparagine and glutamine. On acid hydrolysis these residues break down to ammonia and aspartic or glutamic acids respectively. They remain intact, however, during enzymic hydrolysis and could be located in this way [14].

The final problem was to show which of the half cystine residues were joined together in the intact insulin molecule. For this it was necessary to isolate peptides containing cystine residues and to determine their structure. The method may be summarized as follows:

1. Partial hydrolysis of insulin under conditions in which the disulphide bonds remain intact.

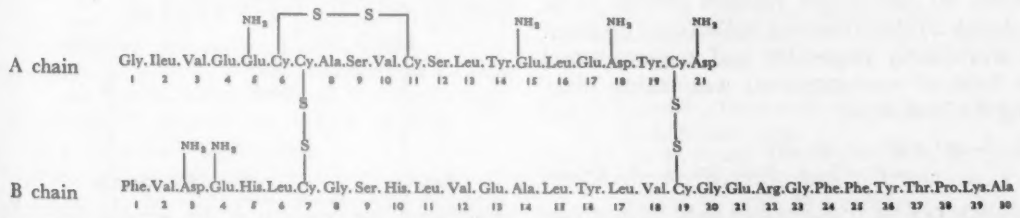

A chain
Gly.Ileu.Val.Glu.Glu.Cy.Cy.Ala.Ser.Val.Cy.Ser.Leu.Tyr.Glu.Leu.Glu.Asp.Tyr.Cy.Asp
B chain
Phe.Val.Asp.Glu.His.Leu.Cy. Gly. Ser. His. Leu. Val. Glu. Ala. Leu. Tyr. Leu. Val. Cy.Gly.Glu.Arg.Gly.Phe.Phe.Tyr.Thr.Pro.Lys.Ala

FIGURE 1 – *Structure of cattle insulin.*

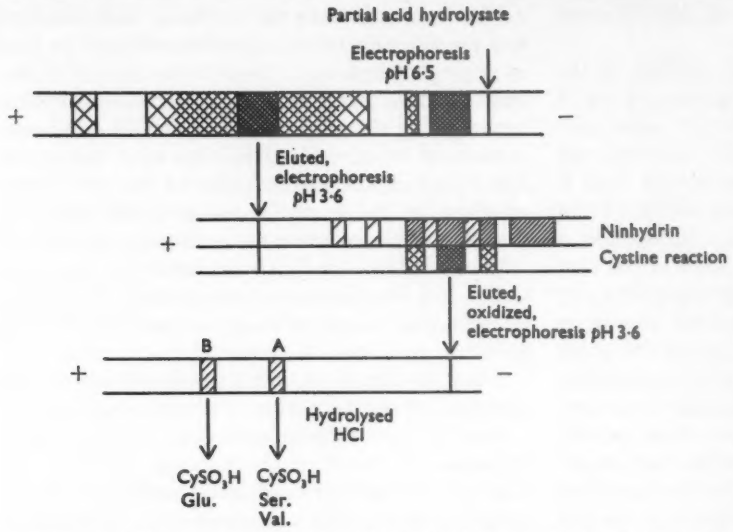
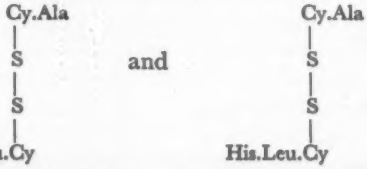


FIGURE 2 – *Diagram showing the method of isolation and identification of a cystine peptide from insulin.*

This reaction was studied in some detail [15], and it was discovered that it could be inhibited by the addition of small amounts of thiol compounds, so that conditions were eventually devised for the isolation of cystine peptides that were in fact fragments of the original insulin. The method of isolation and identification of a typical peptide which gave the position of one disulphide bond is summarized in figure 2.

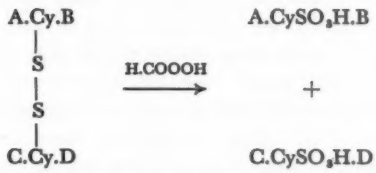
The insulin was first hydrolysed with acid under the special conditions necessary to avoid rearrangement of the disulphide bonds. The peptide mixture was then fractionated by electrophoresis on paper to give a number of bands. These were, however, not yet sufficiently resolved, and so were eluted and subjected to a second electrophoresis at a different *p*H. The position of the peptides was found by using the ninhydrin reagent which reacts with all peptides, and also by using a specific reagent for cystine peptides. In this way a pure cystine peptide was obtained, which was oxidized to give two cysteic acid peptides A and B. These were separated by electrophoresis and each was subjected to complete hydrolysis. From their amino acid composition they were recognized as the peptides Ser.Val.$CySO_3H$ (positions A9–11) and Glu.$CySO_3H$ (positions A5–6) respectively. The original cystine peptide was therefore:

thus establishing the presence of a disulphide bridge between the half-cystine residues in positions A6 and A11. Peptides such as



established the position of the second disulphide bond joining positions A7 and B7. The peptides

2. Separation of cystine peptides from one another.
3. Oxidation of cystine peptides to cysteic acid peptides, e.g.

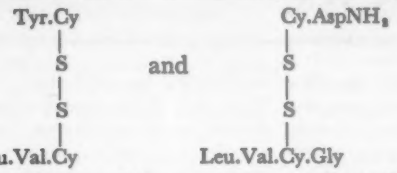


4. Identification of the cysteic acid peptides from the amino acids produced on hydrolysis. These peptides had already been obtained from partial hydrolysates of the A and B chains and therefore their structures and positions in the chains were known. From this the structure of the original cystine peptide and the position of the disulphide bond in the insulin molecule could be inferred.

An unexpected difficulty, however, was that when the peptides were obtained from a partial acid hydrolysate no unique structure could be deduced; all half-cystine residues seemed to be linked with all the remaining half-cystine residues. This was clearly impossible and suggested that some form of rearrangement was taking place during the hydrolysis,

$$R^1\text{—S—S—}R^3 + R^2\text{—S—S—}R^4 \rightarrow R^1\text{—S—S—}R^3 + R^2\text{—S—S—}R^4, \text{ etc.}$$

so that new cystine peptides had been formed that were not true fragments of insulin.



confirmed the remaining one (A20 to B19). These bonds are shown in figure 1, which gives the complete structure of cattle insulin [2, 16].

The structure shown in figure 1 is the structure of a substance which has a unique and characteristic physiological activity, and this raises the problem of the relationship between the chemistry of insulin and its activity. Is the whole of the molecule essential, or does the activity depend on an active centre composed of a limited number of amino acid residues? Studies of chemically modified insulins indicate that the latter is most probable since certain groups, such as the amino groups, may be blocked without loss of activity. The disulphide bridges probably play an important role, since breaking them causes immediate loss of activity. Of particular interest is the intrachain bridge linking positions 6 and 11 in the A chain, since a bridge of the same size is found in two other hormones, oxytocin and vasopressin, which are produced by the posterior lobe of the pituitary gland.

One approach to the problem of determining the reasons for the activity of insulin is by studying insulins from different animals. All insulins show the same activity, so that it might be concluded that any differences found would be in parts of the molecule that are not physiologically important. Sheep, pig, horse, and whale insulins have been studied [17] and were found to have amino acid compositions slightly different from those of the cattle material, but the differences are limited to the positions between the intrachain cystine residue. The various sequences are shown in table II.

TABLE II

The amino acid sequence in positions A7–10 of insulins from various species

Cattle	..	..	$CySO_3H$.Ala.Ser.Val
Pig	..	..	$CySO_3H$.Thr.Ser.Ileu
Sheep	..	..	$CySO_3H$.Ala.Gly.Val
Horse	..	..	$CySO_3H$.Thr.Gly.Ileu
Whale	..	..	$CySO_3H$.Thr.Ser.Ileu

The remainder of the A chain, and the whole of the B chain, are identical in all five species. This suggests that the exact structure of the residues in positions A8–11 is not important for biological activity, but it does not necessarily mean that all the rest of the molecule is essential. Clearly there is still much to be learnt on the question of insulin activity.

Since this was the first protein whose amino acid sequence had been completely determined, it was interesting to see if there were any general scheme underlying the sequence which might prove to be a general principle of protein chemistry. There appears, however, to be no such scheme. Individual residues do not occur at regular intervals along the chains. There are no small repeating units, nor any noteworthy concentrations of similar types of amino acids in any part of the molecule. In fact the arrangement appears to be a completely random one; it is nevertheless a very significant one, since on it depends in some way the unique biological activity of this hormone.

One significant result of this work is that it demonstrates that insulin, and probably other proteins, are homogeneous substances with unique structures and are not merely statistically random polymers of amino acids. This brings the science of proteins into the realms of classical organic chemistry and opens up the way to similar studies on the many other proteins that exist in nature and hence to a better understanding of the chemistry of life.

REFERENCES

[1] HARFENIST, E. J. and CRAIG, L. C. *J. Amer. chem. Soc.*, 74, 3087, 1952.

[2] SANGER, F. *Bull. Soc. Chim. biol.*, 37, 23, 1955.

[3] TURBA, F. 'Hoppe-Seyler/Thierfelder, Handbuch der physiologisch- und pathologisch-chemischen Analyse', 10th edition, 3, 1648, 1955.

[4] DESNUELLE, P. 'The Proteins', edited by H. Neurath and K. Bailey, Academic Press, 1, 87, 1953.

[5] SANGER, F. *Symp. Soc. exp. Biol.*, 9, 10, 1955.

[6] *Idem. Biochem. J.*, 39, 507, 1945.

[7] *Idem. Ibid.*, 44, 126, 1949.

[8] CONSDEN, R., GORDON, A. H., and MARTIN, A. J. P. *Ibid.*, 38, 224, 1944.

[9] THOMPSON, E. O. P. and THOMPSON, A. R. 'Progress in the Chemistry of Organic Natural Products', 12, 270, 1955.

[10] TISELIUS, A. and FLODIN, P. *Advanc. Protein Chem.*, 8, 461, 1953.

[11] MICHL, H. *Mh. Chem.*, 82, 489, 1951.

[12] SANGER, F. and TUPPY, H. *Biochem. J.*, 49, 463, 1951.

[13] SANGER, F. and THOMPSON, E. O. P. *Ibid.*, 53, 353, 1953.

[14] SANGER, F., THOMPSON, E. O. P., and KITAI, R. *Ibid.*, 59, 509, 1955.

[15] RYLE, A. P. and SANGER, F. *Ibid.*, 60, 535, 1955.

[16] RYLE, A. P., SANGER, F., SMITH, L. F., and KITAI, R. *Ibid.*, 60, 541, 1955.

[17] BROWN, H., SANGER, F., and KITAI, R. *Ibid.*, 60, 556, 1955.

Book reviews

KAYE AND LABY

Tables of Physical and Chemical Constants and some Mathematical Functions (*eleventh edition*), *by G. W. C. Kaye and T. H. Laby. Pp. vi + 233. Longmans, Green and Company, London.* 1956. 25*s net.*

'Kaye and Laby' needs no introduction, for since its first edition was published in 1911 it has been found virtually indispensable by many generations of research workers and students. It is sad that neither of the original compilers is still with us, but they would surely approve this new edition, prepared by a small committee under the chairmanship of Professor N. Feather. Although there are, of course, many alterations in detail, and new developments have demanded the inclusion of tables which did not appear at all in earlier editions, the spirit of the original has been well preserved. In particular the 'brief résumés containing references to such books and papers as may profitably be consulted', which were such an important feature of earlier editions, have been retained. 'Kaye and Laby' remains an outstanding work of reference, and it is particularly pleasing to see that so important a book is offered at so reasonable a price.

TREVOR I. WILLIAMS

DESCRIPTIVE ASTRONOMY

Introduction to Astronomy, *by Cecilia Payne-Gaposchkin. Pp. x + 508. Eyre and Spottiswoode Limited, London.* 1956. 50*s. net.*

Though written primarily as a textbook for general courses in descriptive astronomy, the author hopes that this book will serve the purpose of introducing astronomy to the student of the liberal arts. Being herself interested in language, history, and literature she has been at pains to point out the many associations of astronomy with these fields. The book is therefore more readable than textbooks are apt to be, and it should appeal to the general reader who has some interest in astronomy. Little background in either mathematics or physics is required for reading it with profit.

Modern astronomy is to a very large extent concerned with the stars, their properties and constitution, their distribution, their association into clusters and galaxies, and their evolution, whereas formerly the chief interest lay in the solar system and the explanation in detail of the motions of planets, satellites and comets. In most of the older textbooks, relatively small space is given to the stars. In this book the balance is redressed, the emphasis being on stars and stellar systems.

A very balanced account is given of the present state of astronomy. Many current ideas about the evolution of stars and galaxies and various cosmological theories are of a tentative nature and may have to be abandoned in whole or in part. Whether such tentative ideas should be incorporated into a textbook is questionable, but the author has been careful to state that some of the theories she describes may have to be discarded. When this is done, and provided the author is prepared to revise the book at fairly frequent intervals, no harm can result; it should be of interest to the student and general reader to learn about the trend of ideas.

The book is very well illustrated, with many plates and diagrams. The planetary photographs taken at the Lowell Observatory and the photographs of stars and galaxies taken with the 200 in. reflector are of special interest.

H. SPENCER JONES

DIFFRACTION GRATINGS

The Interference Systems of Crossed Diffraction Gratings. Theory of Moiré Fringes, *by J. Guild. Pp. viii + 152. Oxford, Clarendon Press; London, Cumberlege.* 1956. 25*s. net.*

Moiré fringes, so called from their resemblance to *moiré* or watered silk, are frequently observed when two similar and regular patterns are superposed. The fringes formed by comparatively coarse patterns such as those of sieves and printers' process screens can be explained by simple geometry, but those formed by the crossing of diffraction gratings have not hitherto been studied critically, although they were observed by Lord Rayleigh and used by Sir Thomas Merton for demonstrating grating errors.

Mr. Guild's monograph is thus an adventure into unexplored territory, and he has given us a masterly survey of its topography. He develops a perfectly general theory to account for moiré fringe formation with all kinds of gratings, whether they be of the coarse 'slit and bar' type or the finer 'furrowed' type, and shows how the fringes are formed by the interference of diffracted wavefronts. This interference can produce a very wide variety of fine patterns, depending upon the distribution of energy in the various orders of diffraction of the two gratings. The theoretical explanation is well supported by a series of photographs which deserve to be printed on a larger scale.

The book is thus an original presentation of the theory of a new branch of interferometry, and its readers will await with impatience Mr. Guild's promised sequel on its practical implications, particularly in the field of precise measurement.

L. A. SAYCE

LUMINESCENCE

Irradiation Colours and Luminescence, *by Karl Przibram, translated and revised by J. E. Caffyn. Pp. xiv + 332. Pergamon Press Limited, London.* 1956. 63*s. net.*

This expanded version of the 1953 German edition is of much historical interest. It assembles a large amount of information on naturally coloured minerals, and on related artificial effects in synthetic crystals. The descriptive matter is, however, often discursive and too detailed for easy reading. The translator has done much to modernize the book, but could hardly alter its somewhat old-fashioned tone, which will do little to inspire present-day users. Thus the treatment of luminescence relies too much on obsolete ideas; the many added references could evidently not be discussed adequately without much more space.

Part I discusses experimental methods, the production and removal of colour centres in synthetic crystals, and associated theory. Luminescence is considered chiefly as thermoluminescence of coloured crystals, and photoluminescence at centres generated by radiation. Part II describes natural minerals, especially rock salt and fluorite, with the general thesis that natural radioactivity causes the observed colorations. The most valuable sections are perhaps those on natural radioactivity, rare earth activators, and pleochroic haloes; also the reference list, which has about 1300 entries, from Herodotus to 1954. Very few mistakes in reference page numbers have been noticed, but many misprints occur in the book, mostly in authors' names.

S. T. HENDERSON

RADIOACTIVE ISOTOPES

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. *Vol. XV:* Applications of Radioactive Isotopes and Fission Products in Research and Industry. *Pp. viii* + 327. *United Nations, New York; Her Majesty's Stationery Office, London.* 1956. 54*s. net.*

Like all other volumes of these Proceedings, this is well edited and excellently produced. Even those who took part in the Conference may benefit from this edition, as it also contains the papers—half the total—which could not be read at Geneva. As might be expected there is not much entirely new material here, for publication of work on isotopes was never restricted and had been discussed at previous isotope conferences. Nevertheless, the 48 papers offered provide a representative survey, with little overlapping, of the uses of isotopes and fission products in the many diverse fields.

One-third deal with isotopes applied in research, such as in the study of chemical and catalysed reactions, analysis, absorption phenomena, autoradiography, and diffusion. The second part deals with isotopes in control and technology; its contents should be of great benefit to most industries. The final section deals with the application of fission products which are still in the research and development stage. The use of ionizing radiations in many fields is discussed, most emphasis being placed on the sterilization of food; practically all contributions in this field come from the United States.

This volume should prove a very good investment for any industrial research library. H. SELIGMAN

PHYSICAL CHEMISTRY

Physical Chemistry, *by N. K. Adam. Pp. xii* + 658. *Oxford, Clarendon Press; London, Cumberlege.* 1956. 50*s. net.*

Professor Adam's book has been awaited with eagerness, for it is a long time since a university textbook of physical chemistry was published in Britain. As would be expected, it is first-class in its clarity and accuracy, and in particular the balance between experiment and theory is well held. There are many illuminating touches, such as the illustration of Euler's Theorem by the blending of white coffee, and the invention of the term 'chaperon effect' for the removal of surplus energy by a third body. Many sections have short historical introductions, which are excellent in scope and presentation.

The writer of a general textbook of physical chemistry has to decide the selection and arrangement of the topics, and the amount of space to be given to individual examples, matters on which any two teachers of chemistry are certain to disagree. It will seem wrong to many that this book contains only cursory references to modern quantum theory: thus the Schrödinger equation is not solved even for the simplest systems, though some classical derivations of moderate complexity are given in full. The quantum theory of specific heat is treated only qualitatively. The structure of solids is treated fully (50 pages), with many examples, while the whole of thermodynamics and statistical mechanics occupies only 73 pages, very few examples being given. Similarly, the number of examples given of photochemical reactions and of colloid behaviour may seem excessive for a book of this size. R. P. BELL

CHEMICAL ENGINEERING

Mass-transfer Operations, *by Robert E. Treybal. Pp. ix* + 666. *McGraw-Hill Book Company, London.* 1955. 71*s.* 6*d. net.*

Manufacturing operations are commonly concerned with systems in which inter-related changes of physical state and chemical composition take place to the accompaniment of energy and mass transfers from one part of the system to another. The individual changes proceed at characteristic speeds determined by driving forces which in the case of energy transfers may be temperature differences and in the case of mass transfers concentration gradients. One of the aims of chemical engineering science is to determine the mechanism by which such changes take place and to assign quantitative values to them.

Professor Treybal's book is primarily written for students, and as such it presents clearly and simply the quantitative approach to mass-transfer operations. The first five chapters introduce diffusion and mass-transfer theory, on which the subsequent treatment of gas-liquid, liquid-liquid, and solid-fluid operations is based. Brief accounts of current practice in plant design are also incorporated which give reality to the theoretical treatment.

In spite of some misplacement of emphasis and some important omissions, the book is well balanced and comprehensive in scope. References to the literature are adequate and the numerical examples carefully chosen to illustrate major principles.

D. M. NEWITT

CHROMATOGRAPHY

Gas Chromatography, *by Courtenay Phillips. Pp. x* + 105. *Butterworths Scientific Publications, London.* 1956. 25*s. net.*

The sweeping success of the method of gas-liquid chromatography introduced by Martin and James in 1952 has tended to obscure the fact that gas chromatography was successfully practised much earlier. This clear and balanced account by a pioneer in the field is therefore particularly welcome. Although the book is modest in size and in quality of production—more so than its price would indicate—it nevertheless contains a great deal of information and a bibliography comprehensive enough to meet the needs of the advanced worker. The scope of the method is clearly defined, and there is a clear description of the various experimental techniques in general use. Theoretical treatment is not detailed, but is sufficient for an understanding of what happens on the column.

TREVOR I. WILLIAMS

INORGANIC CHEMISTRY

Nouveau Traité de Chimie Minérale, *Vol. I.* Généralités, Air, Eau, Hydrogène, Deutérium, Tritium, Hélium et Gaz Inertes, *edited by Paul Pascal. Pp. xii* + 1101. *Masson et Cie, Paris.* 1956. *Paper covers, Fcs* 7500*; cloth, Fcs* 8400 *net.*

One cannot but admire the enterprise of those responsible for the *Nouveau Traité de Chimie Minérale.* When completed it will consist of nineteen volumes, to appear at intervals from 1956 to 1960. The editor will be assisted by a panel of experts who will deal with the chemistry of the elements in the light of modern ideas of atomic and molecular structure. Technical details of industrial processes will be kept in the background, as the editor considers that this information is already available in specialist publications. The basis of classification is essentially the Periodic Table. The first volume of the series contains a general introduction of some 384 pages dealing with general topics such as the use of diagrams in chemistry, the stable isotopes and the radioactive isotopes of the elements, the structure of the atom and important aspects of modern structural chemistry. The various chapters are illustrated

with excellent diagrams and the information is clear and concise. The remainder of Volume I is devoted to detailed accounts of air, water, hydrogen, deuterium, tritium, helium, and the inert gases. The factual matter chosen for presentation has been selected as critically as possible, and the same applies to the quantitative information. Particularly valuable are the references at the end of each chapter to original work. The reader will find a useful account of the achievements up to date in the subjects covered.

W. WARDLAW

LITHIUM ALUMINIUM HYDRIDE

Lithium Aluminium Hydride in Organic Chemistry, *by V. M. Micovic and M. L. Mihailovic. Pp. xi* + 193. *Serbian Academy of Sciences, Belgrade.* 1955. $3 *net.*

Lithium aluminium hydride has a high available hydrogen content, and readily reduces many functional groups, usually without side reactions, in cold ethereal solution. It is still a matter for wonder that carboxylic acids and esters may be so reduced to primary alcohols, and that the conditions are so mild that racemization of optically active centres does not occur. It was first prepared by Professor Schlesinger and co-workers at Chicago only ten years ago, and its remarkable powers as a reducing agent were first described by Nystrom and Brown in 1947–48. Such, however, are its advantages over other reducing agents that it has now become the reagent of choice. The present monograph contains 1732 references up to October 1954.

This book will prove of great value to all who may wish to use lithium aluminium hydride. Five sections deal with the reagent and the conditions under which it is used; the next nineteen each describe the reduction of a particular group. Among these are carbonyl compounds, acids, esters, lactones, amides, epoxides, peroxides, nitriles, nitro, halogen, and sulphur compounds. Each section gives examples, generously illustrated with formulae and with copious references to the literature; the coverage appears to be complete. The book ends with a section on the mechanism of the reductions, a complete index of references, and a good subject index. W. BAKER

NUCLEAR CHEMISTRY

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. *Vol. VII,* Nuclear Chemistry and the Effects of Irradiation. *Pp.* 691. *United Nations, New York; Her Majesty's Stationery Office, London.* 1956. 70*s. net.*

This volume reports 86 papers from the Geneva Conference of 1955 and the discussions which followed them. It must be regarded, therefore, as essentially a reference book for specialists. However, its main value may well be to workers in the field traditionally called Atomic Energy, who, while not specializing in nuclear chemistry, can benefit from the up-to-date review articles and the wealth of facts and figures so conveniently available. Chemists in general will welcome the survey of nuclear fission by Steinberg and Glendenin and the papers on the formation and chemical properties of the new elements (transuranics). Inorganic chemists will find cause to consult the paper on anion exchange by Kraus and Nelson. The Japanese papers on radioactive fall-out have significance apart from their radiochemical content. Specialists will perhaps be irritated by the choice of title and the curious mixture of contents. 'Nuclear Chemistry' and 'Effects of Irradiation' (meaning radiation chemistry) are very different subjects. Many papers fall in neither category; remote handling, laboratory design, chemical separations and chemical properties do not constitute nuclear chemistry merely because they discuss radioactive substances. Less specialized readers may, however, welcome the mixture. F. BROWN

ORGANIC SYNTHESES

Organic Syntheses, *Vol. XXXV, edited by T. L. Cairns. Pp. vi* + 122. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 30*s. net.*

The present volume details the syntheses of 36 organic compounds. With the immense growth of organic chemistry in recent years it is to be expected that some of the preparations described will be of somewhat limited interest; the syntheses are, however, often important applications of new methods and reactions. On the other hand, several improved methods of making familiar substances are listed. The preparations indicate the availability of apparatus and chemicals in the American scene; spinning-band columns are used for relatively simple fractional distillations; molar quantities of starting materials appear to be easily available; one preparation involves a steam distillation in which 36 litres of water are collected.

The writing is, as usual in this series, clear and eminently suited to the purpose of the book. As in previous volumes, the printing, paper, and binding are excellent. The book is essential to any active organic chemical laboratory. J. C. SMITH

COLLAGEN

The Chemistry and Reactivity of Collagen, *by K. H. Gustavson. Pp. ix* + 342, *and* The Chemistry of Tanning Processes, *by K. H. Gustavson. Pp. ix* + 403. *Academic Press Inc., New York; Academic Books Limited, London.* 1956. $8 *and* $9 *net respectively.*

In the first of these two books the author has used his extensive researches on collagen, in the form of hides and skins, to provide the background of a most able review of our knowledge concerning its structure and reactivity, which is of fundamental importance in biochemistry, medicine, and leather technology. The parts played by X-ray techniques, electron microscopy, and birefringence in revealing the structure of collagen are lucidly discussed, showing the developments since Astbury's first researches. Other chapters deal with the isoelectric points of collagen and its interaction with acids and bases. The relationship between the internal linking of the collagen molecule and its hydration is clearly demonstrated in considering Donnan and lyotropic effects. Very sound chapters discuss the thermal shrinkage of collagen and its relation to cross-linking reactions and also the inactivation of specific groups for studying its reactivity.

The second book, which is of less general interest, deals with the fundamental chemistry of tanning, but does not describe the changes which take place in hides and skins during their conversion into leather. Nevertheless, the chapters relating to the chemistry of chrome tanning, the effects of neutral salts and complexing agents, and the nature of the chrome-collagen compound are of outstanding merit. Much interesting information is given on vegetable tanning, but sufficient stress is not placed on the factors, such as buffer salts, which control the process. Syntan, aldehyde, quinone, oil and combination tannages are also discussed. The final chapter is a definite contribution to our knowledge of the occurrence and mechanism of tanning processes in the animal kingdom and is of importance to biological and medical science. D. BURTON

GEOCHEMISTRY

Physics and Chemistry of the Earth, *Vol. I, edited by L. H. Ahrens, Kalervo Ranhama, and S. K. Runcorn. Pp. viii + 317. Pergamon Press Limited, London.* 1956. 55*s. net.*

This is the first volume of a new series which should be of particular interest to geophysicists and geochemists. There are eight articles which cover a wide variety of topics, each reviewed in a general, rather than a specific, way. To a fairly well read geophysicist or geochemist this particular volume will not reveal much that is new, but it will be a valuable reference work, as each contributor cites many sources and provides a good bibliography.

Sir Harold Spencer Jones gives a short summary of the various theories of the origin of the solar system, from those of Kant and Laplace to the latest ideas of Alfvén and Kuiper. An interesting account of the most recent ideas and facts concerning the thermal state of the interior of the Earth has been written by J. Verhoogen. This article is complemented by K. E. Bullen, who reviews the general structure of the Earth's interior with particular reference to the density distribution. L. H. Ahrens discusses the various isotope-ratio merhods for determining geological age, including the most recent work on potassium-argon, strontium-rubidium, and lead isotopes. R. Hide discusses the hydrodynamics of the Earth's core, with particular reference to the possibility that fluid motions are responsible for the Earth's magnetic field. R. Roy and O. F. Tuttle have written about the results of experiments carried out under hydrothermal conditions, which should be of special interest to the mineralogist and geologist. C. W. Correns describes the work on the geochemistry of the halogens, while S. I. Tomkieff has produced an extensive review and bibliography of recent geochemical work in the Soviet Union. P. M. DU BOIS

PROTOPLASM

The Dynamics of Living Protoplasm, *by L. V. Heilbrunn. Pp. vii + 327. Academic Press Inc., New York.* 1956. $6.50 *net.*

Dr Heilbrunn has spent a lifetime in the study of protoplasm. The first of his papers which he quotes appeared in 1915, and dealt with the physical changes induced in sea-urchin eggs by the methods which lead to artificial parthenogenesis; some of his most recent, written in collaboration with W. L. Wilson, are concerned with essentially the same subject, the changes in the egg cytoplasm during maturation. He has summarized in this book the fruits of the whole of this long period of intensive study of the colloid chemistry and physical properties of protoplasm as it is found in a wide variety of living cells. The book is a highly personal one: it was, as he points out, largely written in the laboratory at intervals between experiments, and perhaps it bears some traces of having been put together from a series of notes. Nearly the whole of it is devoted to expounding and defending his own rather unconventional views. As is well known, he attributes particular importance to reactions which he claims to be of the same nature as the clotting of blood, and which are mainly dependent on the state of the calcium in the system; in these terms he advances explanations of many of the major phenomena seen in living cells. While it is unlikely that many people will accept all his conclusions, it is valuable to have a full discussion of the whole range of his experimental work and the theories he has derived from it.

C. H. WADDINGTON

ENZYMES AND METABOLISM

Enzymes and Metabolism. *Pp.* 287. *Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London.* 1956. 47*s.* 6*d. net.*

This collection of 32 original papers is dedicated to Carl F. and Gerty T. Cori on the occasion of their 60th birthday. At least one of the authors of each paper is, or has been, at the Coris' laboratory. An introduction by Professor Houssay gives a fascinating account of the Coris' scientific activities during the last 35 years. Though the continuous theme of the study of carbohydrate metabolism runs through all their researches, they approached this with a tremendous versatility ranging from physiological work on whole animals, via the study of isolated tissue and of crystalline enzymes, to the chemical characterization of metabolites.

This collection of papers reflects the Coris' activities and covers a very wide range of subjects. Many of them are progress reports of work which was begun or at least inspired in the St Louis laboratory. Biochemists will wish to read most of them. H. GUTFREUND

PLANT PROTECTION

Bibliographie der Pflanzenschutzliteratur, 1951, *edited by J. Bärner. Pp. xliv + 420. Published by Paul Parey, Berlin, for the Biologische Bundesanstalt für Land- und Forstwirtschaft in Berlin-Dahlem.* 1955. *DM.* 38.

This bibliography of literature on plant protection for 1951 continues the well known series which ran from 1914 until 1945; volumes for 1946–50 have yet to appear. Its 12 500 titles certainly include all but a few of the works published in that year, but the accessibility of the information is not all that could be desired. There is an author index, but in the absence of a detailed subject index, reliance must be placed on headings under which the titles are grouped. These are well classified for general purposes. The main sections cover general questions, organisms and causal agents of disease subdivided into orders and families, host plants and their parasites, and control measures. Grouping in this way makes it easy to find all the references, say, to Cruciferae as weeds or to therapy by mercurial derivatives. But it fails to provide specific information. It is not possible, for instance, to obtain references to a particular chemical compound, and to find a species of organism its systematic place must first be known. Nevertheless a work of this kind is always useful to the special librarian. The research worker who wants more specific or up to date information can get it from the numerous abstracting journals which, to some extent, have reduced the value of this bibliographic series.

E. J. MCNAUGHTON

MYCOLOGY

Biology of Root Infecting Fungi, *by S. D. Garrett. Pp. xi + 293. Cambridge University Press, London.* 1956. 30*s. net.*

This book is an excellent exposition of that stimulating approach to plant pathology which has been affectionately called 'Garrettism' by Dr Garrett's former pupils and friends. Dr Garrett sees root diseases not alone as interactions between two organisms but as the resultant of interaction within the matrix of interacting ecological factors. He writes with a hope of interesting biologists, not pathologists alone, and it is apparent from the way in which he takes field problems into the laboratory and laboratory results to the field that Dr Garrett has a courage and tenacity which many plant ecologists would do well to emulate.

There are some general concepts such as inoculum potential, mycelial momentum and competitive saprophytic ability which are formulated and defined in this book. The definitions make use of such phrases as 'energy of growth', 'effective mass', 'summation of physiological characters' which, even if they are not quite scientifically precise and acceptable, are graphic in conveying the desired meaning. The reader will gain a great deal in the effort of trying to redefine these concepts in a more precise manner. J. L. HARLEY

FUNGICIDES

Principles of Fungicidal Action, *by James G. Horsfall. Pp. xix + 279. Chronica Botanica Company, Waltham, Massachusetts; The Chronica Botanica Company, London.* 1956. $6.50.

Much attention has been given in recent years to the relationship between chemical structure and fungicidal activity and to the mechanisms by which fungicides exert their effects. Dr Horsfall, who has played a conspicuous part in these investigations, now earns the gratitude of plant pathologists by reviewing the work that has been carried out and by summarizing the present position.

His book forms a natural successor to his earlier 'Fungicides and their Action'. The principles of the methods of assessing fungicidal activity are fully discussed, and attention is given to aspects of protection such as deposition and the mobilization of fungicide deposits upon plant surfaces. Other sections are devoted to the penetration of fungicides, to the effects of toxicants upon growth phenomena and fungus metabolism, to the chelation of metals, and to the mechanism of action of many kinds of established fungicides. The author's survey of the systemic treatment of plants and his warning of the probable development of resistant fungi are of particular interest.

The book is designed for the specialist and contains a wealth of information, particularly on the types of compound that show activity. It is perhaps marred somewhat by doubtful generalizations and loose phraseology, and by fanciful attempts at popularization that seem out of place in a work of this nature. J. T. MARTIN

METABOLIC PROCESSES

La Régulation des Processus Métaboliques dans l'Organisme, *by Théophile Cahn. Pp. xii + 681. Presses Universitaires de France, Paris.* 1956. *Fcs* 3000.

This book sets out to discuss the hormonal control of the metabolic processes concerned with the supply of energy. The introductory chapter describes the endocrine disorders which can be produced experimentally by removal of the endocrine tissues, or by specific poisons such as alloxan. The next chapter—more than half of the book—deals with the transport of metabolites and its control by hormones. This covers the physiology of the blood sugar, of fat absorption, of blood lipids, of the nitrogenous substances, and very briefly of inorganic salts and water. Then follows a description of the physiology of energy release and of the interconversion of carbohydrate, fat, and proteins. The role of the nervous system in the control of metabolism, though briefly mentioned, is not discussed.

The approach throughout is that of the classical physiologist. Only occasionally is reference made to details of intermediary metabolic processes, and enzymes are hardly mentioned, not even in connection with the mechanism of action of insulin. In his preface the author points out that this limitation is deliberate. The book centres round the author's own research experience during the past 25 years, and as a coherent record of his viewpoint it is certainly a valuable addition to the literature.

H. A. KREBS

NUCLEAR REACTORS

Principles of Nuclear Reactor Engineering, *by Samuel Glasstone. Pp. ix + 861. Macmillan and Company Limited, London.* 1956. 60*s. net.*

This authoritative work, sponsored by the United States Atomic Energy Commission, is an important addition to the growing volume of literature for engineers in the nuclear energy field; it is intended both for practising engineers and for senior or post-graduate engineering students. Dr Glasstone had the assistance of staff of the Oak Ridge National Laboratory, and has given a broad and comprehensive review of the scientific basis of reactor design, construction, and operation.

About one-third of the book is devoted to the fundamental physics of reactors, with chapters on the relevant aspects of nuclear reactions and radiations and on reactor theory in equilibrium and non-equilibrium conditions. Specific aspects of reactors are then treated in turn: instrumentation and control, chemical processing of fuel, materials, radiation protection, shielding, and heat generation and transfer. There is a chapter on design variables, in which many of the possible types of reactors are discussed, and a series of descriptions of particular installations.

The material is excellently arranged. Each chapter is followed by definitions of the symbols used in the text, and by a set of problems. There are many references and suggestions for more detailed reading, and a good index.

T. G. PICKAVANCE

REACTOR TECHNOLOGY

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. *Vol. IX,* Reactor Technology and Chemical Processing. *Pp. x + 771. United Nations, New York; Her Majesty's Stationery Office, London.* 1956. 70*s. net.*

This volume is predominantly of interest to the chemist and metallurgist. It deals with the metallurgy and fabrication of fuel elements, with liquid-metal heat-transfer media, and with the chemical aspects of atomic energy such as corrosion, processing of fuel and fission products, and waste disposal problems.

This is one of the most important volumes of the Geneva Conference series. Nearly all the material presented had been treated as secret almost up to the date of the conference, while the cost of the research and development described must have been some tens of millions of pounds. For this reason the origin of the papers is of some significance: 53 from the United States, 16 from Great Britain, 16 from the rest of Europe, only 3 from the U.S.S.R.—an insignificant proportion compared with the Soviet contribution on less secret subjects such as radiation studies and isotope research.

To the scientist or technologist concerned with atomic energy almost all the papers are of the greatest value. But a large number of new fields have been explored, such as the chemistry and metallurgy of some rarer elements, new methods of chemical analysis, and new chemical engineering techniques, particularly for the separation and purification of inorganic salts by solvent extraction. Many of these unconventional treatments, now that they have been developed, can with advantage be applied to other branches of research and industry. E. GLUECKAUF

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books discussed.)

Elementary Wave Mechanics (*second edition*), *by W. Heitler. Pp. viii + 193. Oxford: Clarendon Press. London: Cumberlege.* 1956. 18*s. net.*

This is a second edition of a book for non-mathematical readers the success of which is indicated by the fact that it has been five times reprinted since it first appeared in 1945. The new edition includes a section on diatomic molecules, and the chapters on the chemical bond have been much extended. A section on the time-dependent wave equation has also been added.

Physical Chemistry (*second edition*), *by W. J. Moore. Pp. xii + 633. Longmans, Green and Company, London.* 1956. 30*s. net.*

This textbook of physical chemistry, first published in 1950, is designed for students of science and engineering. It is rather more than an elementary work, and assumes in the reader a knowledge of calculus and some two years' systematic study of both physics and chemistry. This new edition follows the general lines of the first, but there have been in every chapter corrections of detail and changes in presentation. A new chapter on photochemistry has been added, and recent advances in nuclear, atomic, and molecular structure are described.

Cumming and Kay: 'Quantitative Chemical Analysis' (*eleventh edition*), *revised by Robert Alexander Chalmers. Pp. xvi + 540. Oliver and Boyd, Edinburgh.* 1956. 30*s. net.*

This well known textbook of quantitative chemical analysis, now in its eleventh edition, is designed primarily for the use of university students. The last edition appeared in 1948, and this new one represents a thorough revision. Major alterations include the rewriting of the section on colorimetry and the addition of a short account of the theory of precipitation and contamination of precipitates. An innovation is the inclusion of short reading lists.

Organic Chemistry (*third edition*), *by Louis F. Fieser and Mary Fieser. Pp. v + 1112. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 50*s. net.*

This is the third edition of a well known textbook of organic chemistry, which has been thoroughly revised—and in many parts rewritten—to take note of the many new enlargements in both theory and practice that have taken place since the second edition appeared in 1950. The number of reaction mechanisms considered has been increased, and each is discussed as the reaction is encountered in the text. A feature of the book, adapted from the German translation of the second edition, is the inclusion of some 450 brief biographical sketches of the principal chemists, past and present, whose work is discussed.

Essays in Biochemistry, *edited by Samuel Graff. Pp. x + 345. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 52*s. net.*

These twenty-seven essays, covering a wide field, were written in honour of Hans Clarke, by some of his former students and academic associates, on the occasion of his retirement. They are in the main neither reviews nor experimental reports. Some are critical assessments of contemporary biochemical problems, others are frankly speculative: all are authoritative and include extensive bibliographies.

Learning and Instinct in Animals, *by W. H. Thorpe. Pp. viii + 493. Methuen and Company Limited, London.* 1956. 55*s. net.*

In recent years ethological research workers have tended to follow one or other of two quite distinct lines. Either instinct has been studied, especially in Europe, or learning, especially by American workers using laboratory-bred animals. This book represents an attempt to integrate these two different methods of approach to the subject. The first part of the book deals with general principles. The remainder surveys the part played by learning in the organization of the behaviour of the principal groups of animals, from the Protozoa to the Mammals.

The Private Life of Fishes, *by M. Constantin-Weyer (translated by R. Turrell). Pp.* 149. *Richard Bell, London.* 1956. 15*s. net.*

This is a discursive account of the life and habits of fishes, written in a popular style and intended primarily for the naturalist and angler but suitable also for the general reader. Among the topics discussed are the breeding, growth, migration, and vision of fishes.

Histamine: Ciba Foundation Symposium, *in honour of Sir Henry Dale, edited by G. E. W. Wolstenholme. Pp. xvi + 472. J. and A. Churchill Limited, London.* 1956. 50*s. net.*

This book is the edited record of papers read and discussions held by an international gathering of physiologists and pharmacologists in London in 1955. It is divided into two parts. First, the proceedings of a symposium organized jointly by the Physiological and the Pharmacological Societies; second, a less formal symposium on the same subject sponsored by the Ciba Foundation. It deals comprehensively with current research developments in the study of histamine and related substances.

Internal Secretions of the Pancreas: Ciba Foundation Colloquia on Endocrinology, *Vol. 9, edited by G. E. W. Wolstenholme and Cecilia M. O'Connor. Pp. xii + 292. J. and A. Churchill Limited, London.* 1956. 40*s. net.*

This is an account of the proceedings of a colloquium on internal secretions of the pancreas, organized by the Ciba Foundation and held in London in June 1955. It includes both the text of the seventeen papers read and a full account of the discussion which followed each of them. The papers cover a wide field, and the volume should prove of interest to medical research workers, biochemists, and biologists.

High-temperature Technology, *edited by I. E. Campbell. Pp. xiv + 526. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 120*s. net.*

A symposium on 'High-temperature materials, methods, and measurements', organized by the Electrochemical Society in Washington in 1951, indicated the need for a comprehensive work on high-temperature technology. This book, the joint effort of thirty-five contributors, is designed to meet this need. It describes new materials, methods of production, and the measurement of physical properties. In general, high temperatures are taken in the present context to be temperatures above 1500° C.

Notes on contributors

F. P. BOWDEN,
C.B.E., Sc.D., F.R.S.,

Was born in Tasmania in 1903 and became Demonstrator in Physics, University of Tasmania. In 1927 he came to Gonville and Caius College, Cambridge, of which he is now a Fellow; he is Director of Studies and University Reader in Physical Chemistry. During the last war he worked for the Australian Government, and in Melbourne at the Tribophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization. His researches have dealt with the properties of metals and of solid surfaces and with decomposition in the solid state. He has published 'The Friction and Lubrication of Solids' (with D. Tabor) and 'The Initiation and Growth of Explosion in Liquids and Solids' (with A. Yoffe). He is Vice-President of the Faraday Society and was recently awarded the Redwood and the Cresson Medals of the Franklin Institute for his work on friction.

N. MILLOTT,
M.Sc., Ph.D.,

Was born in 1912 and studied at the Universities of Sheffield, Manchester, and Cambridge. From 1938 until 1947 he held an appointment as Lecturer in Zoology in the University of Manchester. In 1948 he was appointed to the Chair of Zoology in the then newly created University College of the West Indies, resigning in 1955 on appointment to a Chair of Zoology in the University of London, tenable at Bedford College. His earliest research dealt with the digestive system of nudibranch molluscs, followed by work on the nervous control of the viscera in *Lumbricus*. For the past eight years he has studied the sensitivity to light and the pigmentation of various animals, especially echinoids. During this time he has held both Carnegie and Guggenheim Fellowships in the United States.

E. N. DA C. ANDRADE,
D.Sc., Ph.D., LL.D., F.R.S.,

Was born in London in December 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914–18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain professor of physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France*. He is known for the clarity of his exposition of science, both in writing and by lectures.

J. M. M. PINKERTON,
M.A., Ph.D.,

Was born in London in 1919 and educated at Clifton College and Trinity College, Cambridge. During the last war he was employed on government radar projects at the Telecommunications Research Establishment in Swanage and Malvern. He returned to Cambridge in 1945 to do research in ultrasonics at the Cavendish Laboratory. Since 1949 he has been in charge of the engineering development of the electronic computers LEO I and LEO II. His publications include various papers on ultrasonic absorption in liquids and on electronic computers.

JAMES PATON,
M.A., B.Sc., F.R.S.E.,

Was born in 1903 and educated at Beath High School and Edinburgh University. After a year in the Meteorological Office he became lecturer in the Department of Natural Philosophy, Edinburgh University, in 1928, senior lecturer in 1950, and reader in 1954. He is corresponden for Section IV (Aurora and Airglow) of the British National Committee for the International Geophysical Year and Director of the Aurora and Zodiacal Light Section of the British Astronomical Association.

F. SANGER,
B.A., Ph.D., F.R.S.,

Was born in 1918 and was educated at Bryanston School and the University of Cambridge. Since graduating in 1939 he has carried out research in the Department of Biochemistry, Cambridge. From 1944 until 1951 he held a Beit Memorial Fellowship for Medical Research and since 1951 has been a member of the external staff of the Medical Research Council. His work has been largely concerned with the chemical structure of proteins, especially of insulin.

L. F. SMITH,
Ph.D.,

Was born in 1927 and was educated at Bede Grammar School, Sunderland, and Imperial College, London. Carried out research on wool chemistry at Imperial College before moving to the Department of Biochemistry, Cambridge, where he is now working as a member of the external staff of the Medical Research Council.

X